

Tube Mills

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1. INTRODUCTION

The mechanical elements of a tube mill can be subdivided into internal and external parts.

The external parts of a standard tube mill consist of mill shell, mill heads, mill bearings, feed and discharge equipment and include also the mill drive.

The internal parts have a direct function with regard to the grinding process and include principally the wear parts of a mill such as mill liners, diaphragms and grinding media.

This paper treats first the external parts and afterwards the internal parts of the tube mill. Special attention has been paid to the process technological aspects.

2. GRINDING WITH TUBE MILLS

The rotation of the mill tube causes the charge consisting of grinding media and feed material to be lifted due to centrifugal forces and friction between the media and the lining. The height to which the charge is lifted depends on a number of factors:

- ◆ liner design
- ◆ circumferential velocity of the mill
- ◆ shape, size and weight of the grinding media
- ◆ friction between the lining and the grinding media
- ◆ friction within the mill charge itself

The media performs a **cataracting motion** as can be seen in Figure 1a if the speed of rotation of the mill is sufficiently high, the loading percentage is appropriately chosen, the ball charge is relatively coarse and lifting liners are installed.

The feed material is ground mainly by impact in the zone "A", where almost the entire energy of the falling grinding media is concentrated. This form of comminuting action is especially effective in the primary size reduction of relatively coarse feed material supplied to the mill (chamber 1 or coarse grinding compartment).

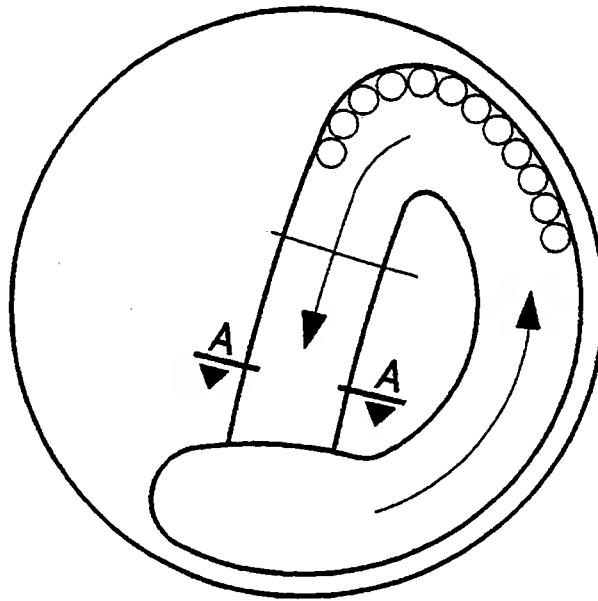
Under similar conditions, but with a finer ball charge and without lifting liners the grinding media will perform a cascading motion as can be seen in Figure 1b.

In cascading the motion of the grinding media in their downward stream is characterized by flowing and rolling rather than falling. This motion of the grinding media causes friction forces. For this reason, cascading is not very suitable for the comminution of coarse feed material, but is on the other hand very effective for fine grinding (chamber 2 or fine grinding compartment).

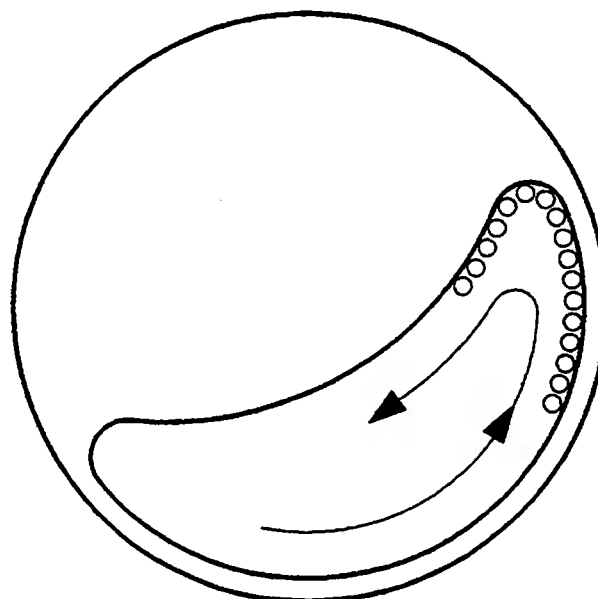
Through the design of liners, the composition of the grinding media charge and the loading percentage of the mill it is possible to modify the motion of the grinding media so as to adapt it to the operating conditions in any given case.

Figure 1 Grinding with Tube Mills

a) Cataracting of grinding media (Chamber 1)



b) Cascading of grinding media (Chamber 2)



3. MILL TYPES

Since there is a various number of ball mill setups a subdivision according to the following characteristics can be made (Fig. 2):

- ◆ type of material which is being ground
- ◆ number of chambers (drying or grinding)
- ◆ method of material transport at mill outlet
- ◆ point of discharge
- ◆ grinding process

The different characteristics can be commented as follows:

3.1 Type of material being ground

The majority of today's installed tube mills are used for grinding cement. Besides cement a variety of other materials are being ground in tube mills such as raw meal, coal etc.

3.2 Number of chambers

A modern cement mill can consist of two or one chamber. Raw material mills are often equipped with one drying compartment to evaporate the water contained in the raw material and one or two grinding chambers. The drying compartment is provided with lifters to obtain a dispersion of the material to be dried. Ball mills with only one chamber are mostly applied in grinding circuits where the material enters the mill preground or raw mills for easy grindable raw material.

3.3 Material transport

There are basically two ways of transporting the material after leaving the mill.

The so called airswept mills carry the material pneumatically to the separator and are not equipped with a bucket elevator. This type of mill is only chosen if a high airflow is needed for the drying of very wet raw materials (or coals). The mechanical material transport by bucket elevators is more economical.

3.4 Discharge point of material




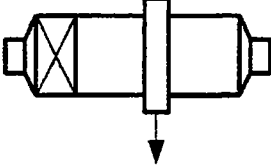
The discharge point of the material can be located at the mill end (end discharge mill) or in the centre (centre-discharge mill). With the exception of wet grinding mills where no airflow takes place the material and the air leaves the mill either at the mill end or at its centre.

3.5 Grinding process

Two grinding processes are applied in existing raw grinding plants, wet grinding (slurry mills) and dry grinding.

Since vertical roller mills are more economical than ball mills and also have the ability to dry extremely wet materials the ball mills were not considered in the latest evaluations of raw grinding plants. However ball mills are still common in wet grinding plants.

Figure 2 Overview Tube Mills

Characteristics	Classification			
Material	Cement	Raw meal	Coal	Others
Number of chambers	<div>1</div> <div>1</div>	<div>1 2</div> <div>2</div>	<div>1 2 3</div> <div>3</div>	
Material Transport	 <p>Mechanical</p>		 <p>Pneumatical</p>	
Discharge point of material				
Grinding process	Dry		Wet (Slurry)	

4. ELEMENTS OF TUBE MILLS

The following table and the according drawing (Fig. 3) show the classification (division) of the mechanical elements and their location on the example of a two compartment tube mill.

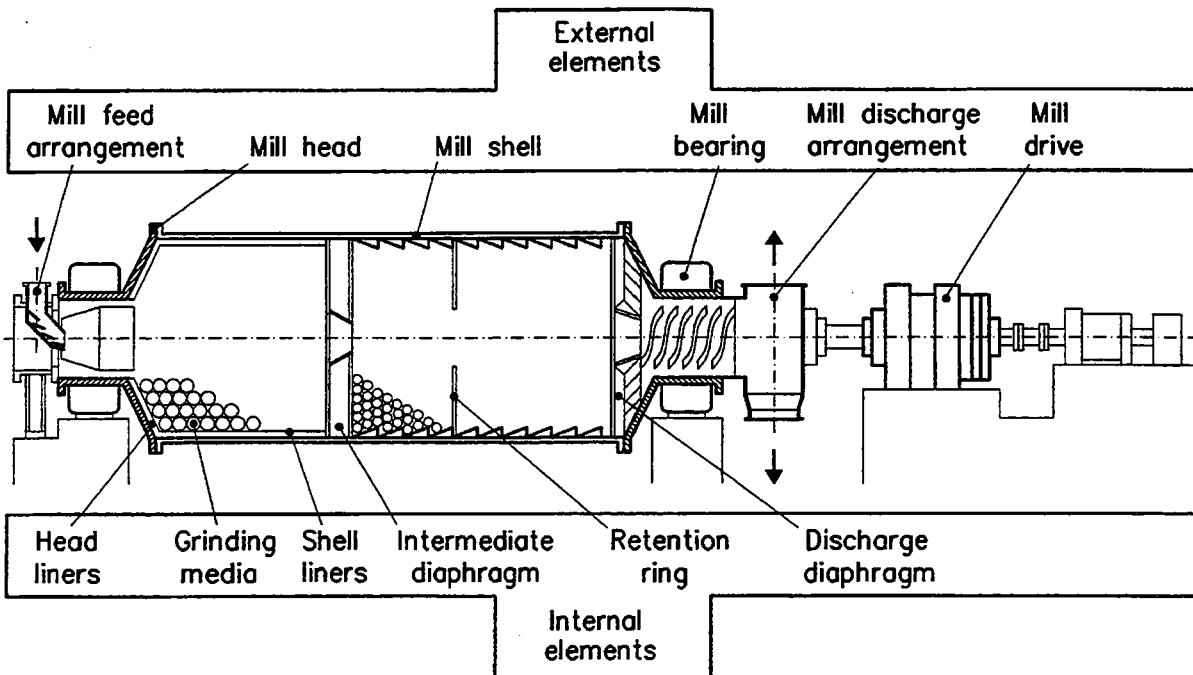
The external elements are introduced first in chapter 5. The internal elements follow in chapter 6.

feed arrangement	head liners
discharge arrangement	shell liners
mill shell	intermediate
mill heads	diaphragm
mill bearings	discharge
mill drive	diaphragm
	retention rings
	grinding media

The dimensions and design of the mill shell, the mill heads and the mill bearings are basically dictated by the required grinding capacity whereas the design of the feed and discharge devices are selected according to process considerations such as wet grinding, dry grinding or drying-grinding.

The internal elements are the so called wear elements. They have a direct influence on the grinding process.

Figure 3 Elements of Tube Mills Overview



5. EXTERNAL ELEMENTS

5.1 Feed arrangements

The feed devices have to fulfill the following functions:

- ◆ enable the material to flow into the mill continuously and without building blockages
- ◆ prevent the back-spillage of material
- ◆ permit the intake of cold ventilation air in case of cement mills
- ◆ permit the intake of hot gas in case of raw grinding mills

There are different types of feed arrangements which meet above listed requirements. A selection is shown in Figure 4 and explained below.

5.1.1 Spout feeder

This type of feeder is applied on slurry mills and on older small cement mills. The limited cross section permits only a small intake of venting air in case of dry grinding.

5.1.2 Drum feeder

FLS provides their tube mills for wet and dry grinding with a drum feeder. The disadvantage of this feed device is its high pressure loss which appears in the dry grinding process where the mill should be ventilated.

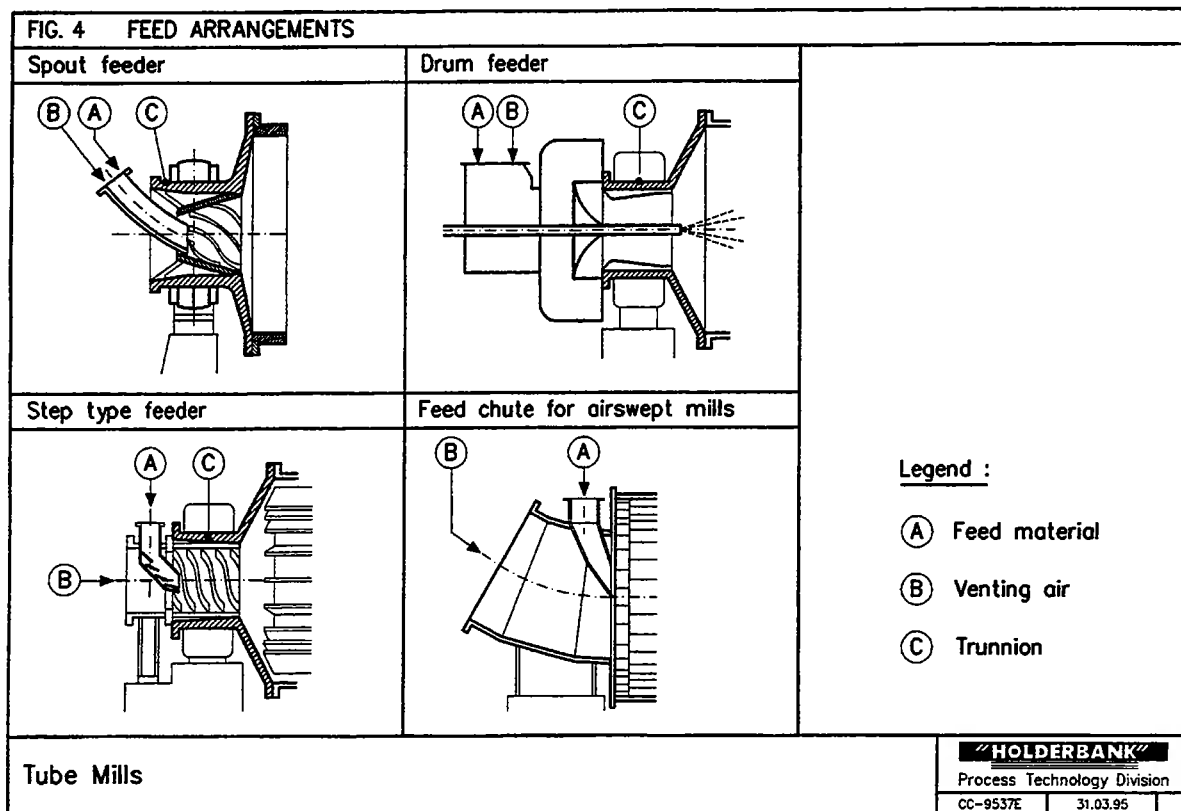
5.1.3 Step type feeder

This type of feeder is used where high venting air or high amount of drying gas is required. The big opening gives a low pressure drop. The air can also find its way into the mill by passing in between the steps.

5.1.4 Feed chute of airswept mills

The mill has its name from the way of transporting the raw material. The ground material is swept out by the mill exhaust gases. This requires a high gas flow rate within the mill. Therefore its inlet device is designed to meet this requirement. The raw material is fed into the gas stream entering the mill. To prevent the intake of false air the feed inlet has to be sealed by pendulum flaps or by rotary valves.

Figure 4 Feed Arrangements



5.2 Discharge arrangements

5.2.1 Centre discharge

The centre discharge is located between the coarse and the fine grinding compartment of a tube mill (Fig. 5). The mill is fed from both sides through its hollow trunnions. The material leaving the coarse and fine grinding compartment is led together through a elevator to a separator.

The separator fines are the final product. The coarses are transported back to the fine, or to both grinding compartments.

At the discharge itself the material leaves the mill through outlet holes in the mill shell. The material is then collected by a casing which is located around the mill shell.

The ventilating air also leaves the mill through the outlet holes.

5.2.2 End discharge

The material leaves the mill through the hollow trunnion at the mill discharge side.

The outlet casing includes a sealing which is located between the rotating and static parts. A steady under-pressure prevents the escape of dust.

Inside this outlet casing the first separation of venting air and ground material takes place.

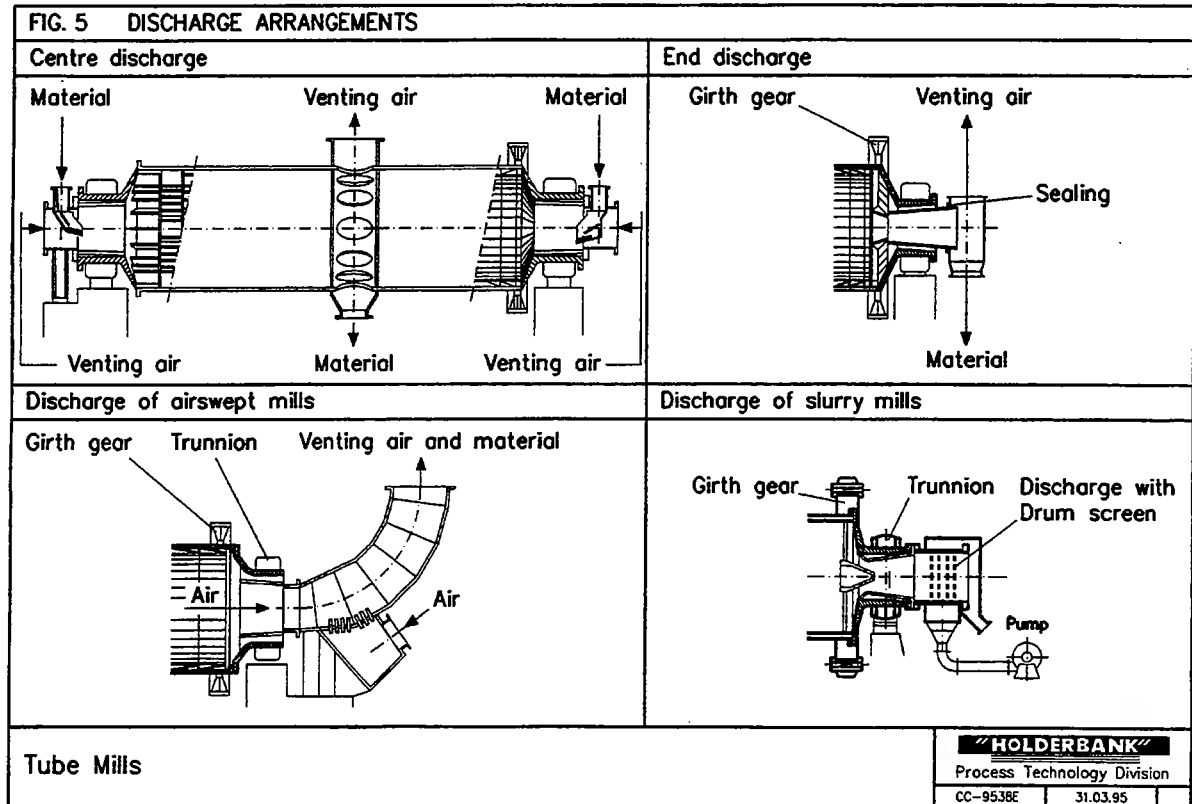
5.2.3 Discharge of airswept mills

The ground material leaving an airswept mill is transported only by gas. Therefore the discharge arrangement must be in a way that the gasflow is not hindered and causes no excessive pressure losses and no accumulation of material takes place.

5.2.4 Discharge of slurry mills

The most slurry mill discharge arrangements are equipped with a drum screen. Slurry mills are installed in open and closed circuits. The rejects (nips) are led back to the mill inlet in case of a closed circuit grinding plant.

Figure 5 Discharge Arrangements



5.3 Mill shell

The mill shell consists of several sections of welded plates.

The thickness of the shell is determined by the weight of the material, the grinding media and the rotating parts and the design of the mill. The shell thickness of long mills is graded, i.e. the thickness increases from both ends towards the mill centre.

The stress distribution within the mill shell can roughly be estimated by using a simplified load distribution model, where the total rotating weight presents the sum of the material, the grinding media and the rotating parts.

The stresses are maximum at the centre of the shell and minimum at the ends.

For the listed shell material qualities the maximum admissible bending stresses for the different types of mills can be found in Figure 6.

5.4 Mill heads

Tube mills supported with trunnion bearings are provided with mill heads. The heads are bolted or welded to the mill shell.

Small mills are often equipped with one piece mill heads (integral heads) where the trunnion and the mill head are cast as one piece. They are bolted to the flange of the mill shell as shown in Figure 7-1.

Trunnions can also be bolted to the mill heads as indicated in Figure 7-2. The mill head in this example is directly welded onto the mill shell.

The mill heads of large mills are mostly divided concentrically into an outer and an inner part (Figure 7-3).

The inner conical part of the head can either be cast together with the trunnion or it is jointed to each other by welding.

The outer part is bolted to the inner part and welded to the mill shell.

In order to entirely relieve the mill heads of large mills of the elevated bearing reaction forces, there is a certain trend to use slide shoe bearings in conjunction with a riding ring mounted to the mill shell. The mill head consists in this case of a welded construction of mild steel plates (Figure 7-4).

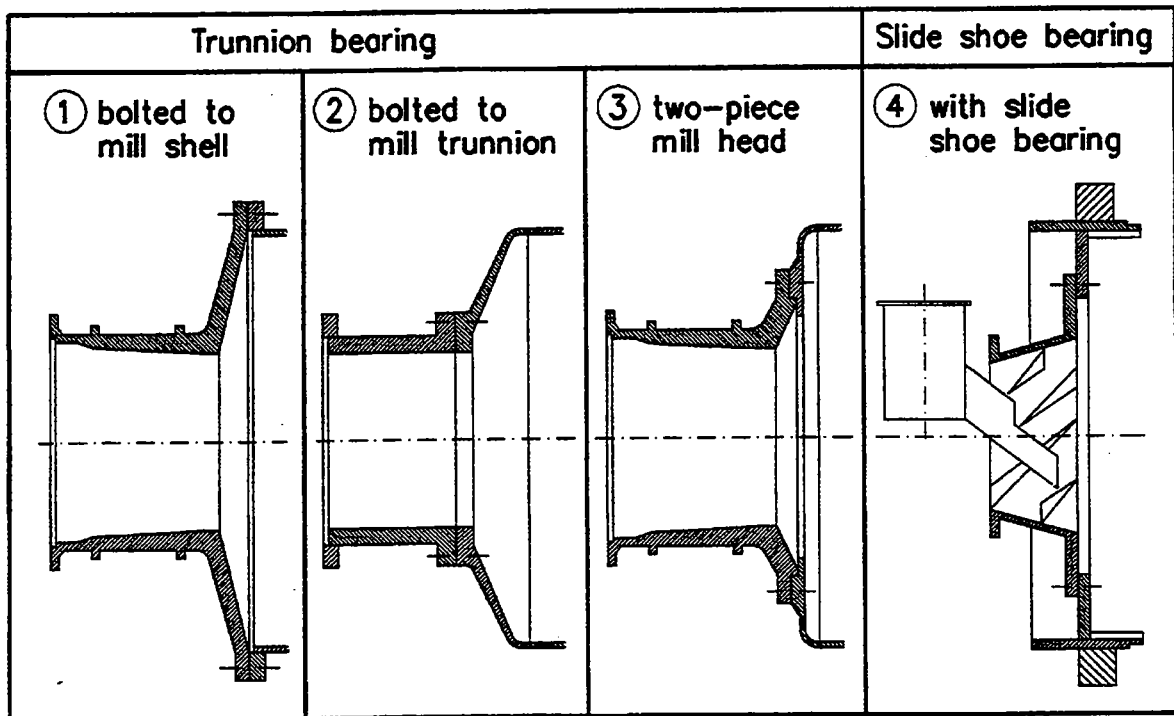
The mill heads can be cast from modular cast iron. However a cast steel with a low sulphur content is often preferred to permit a proper welding of the mill heads to the mill shell.

Figure 6 Mill Shell

Mill shell Material	– Boiler plates HI – St 37-3 (DIN 17155) with low sulphur content – ASTM A 283 grade C with carbon content <0,2% (USA)
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Type of mill	Max. admissible bending stress (N/mm ²)	
	With trunnion bearings	With slide shoe bearings
End discharge		
Mill ø < 4,2m	16 – 18	9 – 10
Mill ø < 4,2m	12 – 14	
Centre discharge	6 – 8	

Figure 7 Mill Heads



5.5 Mill bearings

5.5.1 Trunnion bearing

The hollow trunnions of tube mills are supported by trunnion bearings (Fig. 8). The bearing comprises a welded or cast casing with the bearing liner, the supporting insert mounted on spherical surfaces, the white metal lined bearing liner and the lubricating and cooling equipment.

Trunnion bearings are hydrodynamically lubricated and support approximately 30 - 50 % of the mill head trunnion. During the starting and shut-down period high pressure pumps float the bearings (hydrostatic lubrication).

This is because there is a critical zone between the mill end and the trunnion where severe stresses occur. The fabrication of the mill ends requires special precaution to ensure sound component quality with an extended life.

5.5.2 Slide shoe bearing

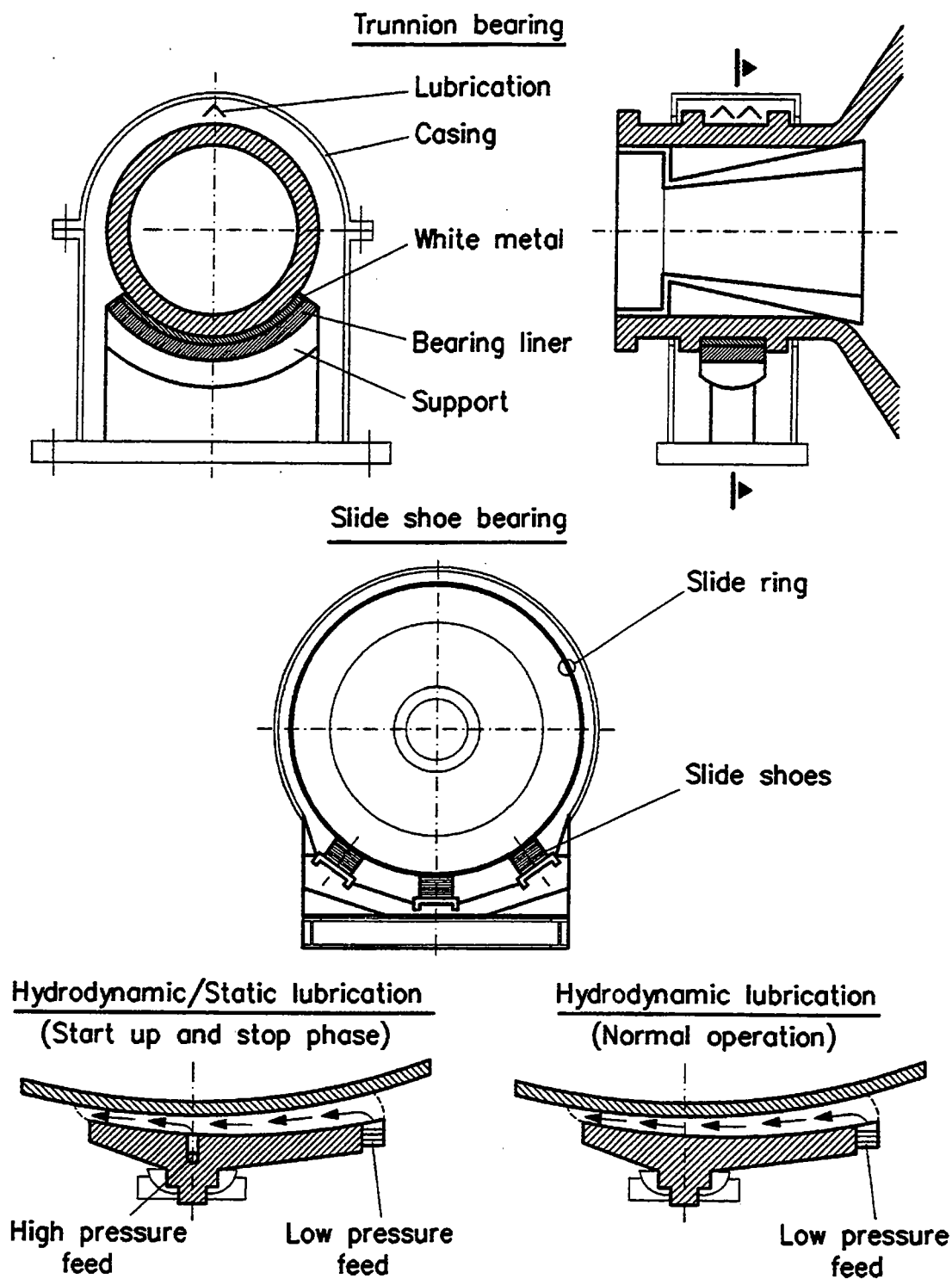
The slide ring (or riding ring) rests on a set of self adjusting sliding shoes as shown in Figure 8. Hydrostatic lubrication is provided for the start-up phase and hydrodynamic lubrication during operation.

The main advantages of slide shoe bearings as compared with trunnion bearings are:

- ◆ no limitation in size and capacity of mill
- ◆ no delicate large size mill head castings are necessary
- ◆ simple design of wear plates
- ◆ simplification of feed and discharge devices
- ◆ large feed and discharge openings allowing the passage of considerable amounts of gas

- ◆ no limitation in gas temperature influencing expansion of trunnion and trunnion bearing

Figure 8 Mill Bearings



5.6 Mill drives

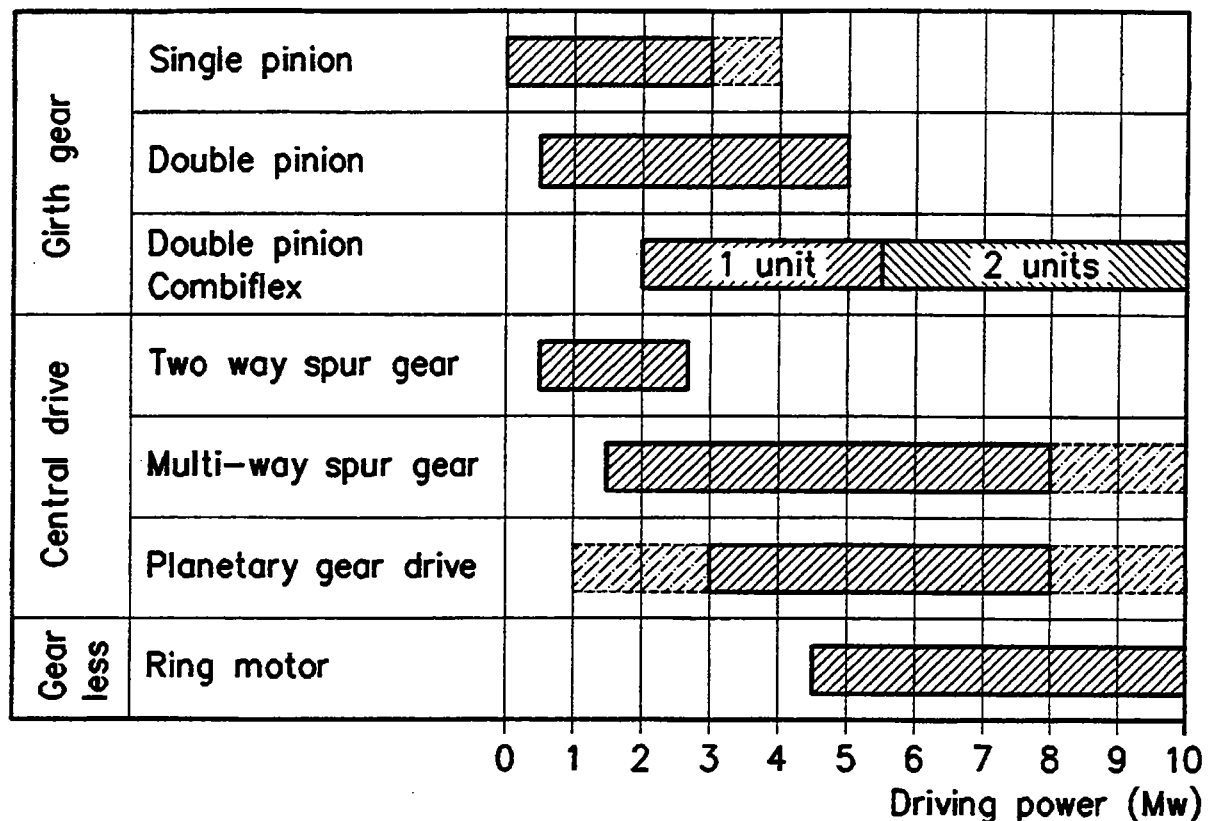
5.6.1 General

The mill drives can basically be subdivided into three groups:

- ♦ girth gear / pinion drives
- ♦ central drives
- ♦ gearless drives

Each type can be applied for a certain range of power as indicated in Figure 9.

Figure 9 Power Ranges of Mill Drives



5.6.2 Girth gear / Pinion drives

The girth gear (or spur rim) is bolted to the mill body and is driven either by one or two pinions as shown in Figure 10 a. The reduction gear box arranged between pinion and mill motor is equipped with an auxiliary drive. The auxiliary drive allows slow rotation of the mill ($0.2 - 0.3 \text{ min}^{-1}$) for inspection or to turn the mill to a certain position.

Girth gear drives are often used for mills which are designed for high drying capacities which due to the large required outlet cross section do not permit the use of central drives.

The girth gear is enclosed in an oil-tight casing and is spray or splash lubricated.

Girth gears are made from Cr-Mo heat treatable cast steel hardened to max. 900 N/mm^2 tensile strength. The pinions are generally made from Cr-Ni-Mo heat treatable steel hardened to max. 1150 N/mm^2 tensile strength.

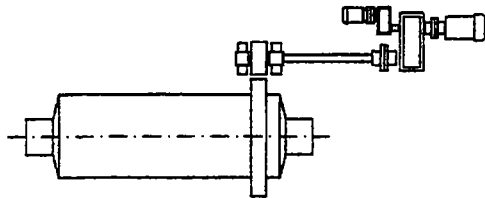
US suppliers often prefer a low speed synchronous motor instead of a reduction gear.

Double pinion drives can be used where a driving power of up to 5000 kW needs to be transmitted. The Combiflex presents a good solution for driving powers above 5000 kW.

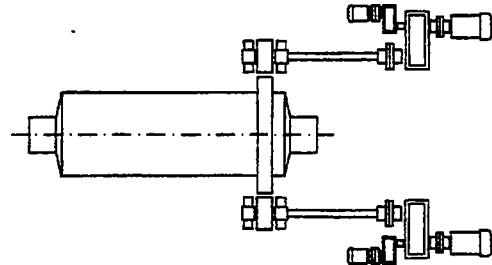
One Combiflex gear consists already of two pinions. If two units are installed, four pinions transmit the forces to the girth gear. This design allows to install driving powers above 10'000 kW. A further characteristic of the Combiflex is that the girth gear and the slide shoe ring are located next to each other and covered by the same casing.

Figure 10a Types of Mill Drives

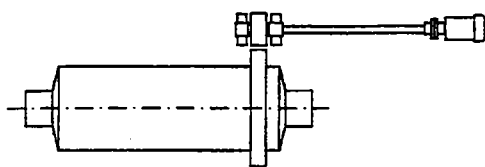
Single pinion girth gear drive



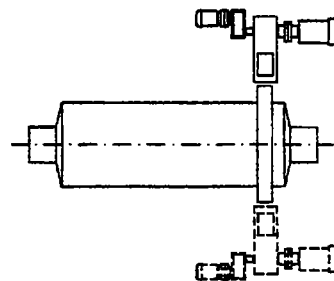
Double pinion girth gear drive



Single pinion girth gear drive with synchronous motor



Double pinion (Combiflex)



5.6.3 Central drives

The gear unit of a central drive can either be coupled by a hollow shaft, by a torsion shaft or directly to the mill. The gear is operating in an oil-bath in a completely enclosed casing.

Smaller existing mills with input powers up to 3'000 kW are equipped with a two way spur gear with either one or two motors, Figure 10b.

For larger driving power either a multi-way spur gear or a planetary gear could be used.

Multi-way spur gears (e.g. FLS "Symetro" gear or Flender "Polyflex" gear) are manufactured in sizes up to 10'000 kW.

Single motor planetary gears are built up to 8'500 kW. For higher power ratings up to 10'000 kW dual planetary gears are available. The planetary gears are generally more expensive than multi-way spur gears, offer however a very high gear efficiency and are of a very compact design.

The planetary gear drive where the gearbox is flanged to the mill (MAAG) has no direct contact with the mill foundation, i.e. mill movements or any lowering of its foundation have no effect on the gearbox teeth. This planetary gearbox requires only a little support for the torque arm.

5.6.4 Gearless drives

Large tube mills can be driven by low frequency electrical motors; the so-called ring motors or wrap-around motors. The ring motor is directly arranged around the mill shell; i.e. there is no speed reducer required.

For the required low mill speed of 13 - 15 min⁻¹ a speed adjustable AC drive with a frequency of 5-6 Hz is used.

The motor can be supported by an extended mill head or it can be arranged on the mill shell according to Figure 10c.

The ring motor can be accelerated from standstill up to operation speed. For a limited time the mill can be turned with a very low speed to allow a positioning of the manholes in the mill shell.

The main advantages of the ring motor as compared with conventional mill drives are:

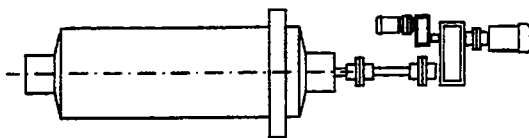
- ◆ adjustable mill speed
- ◆ no wearing part on gearless mill drive
- ◆ no costly lubrication required
- ◆ low mechanical maintenance costs
- ◆ no limitations for larger tube mills
- ◆ more flexible layout of mill room

The disadvantages include mainly:

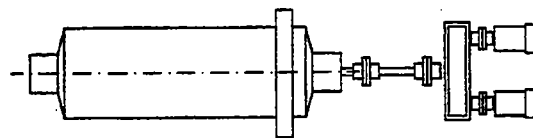
- ◆ low efficiency (91 - 92 %)
- ◆ higher investment cost (for small units)
- ◆ extra load (15 %) on mill bearing due to weight of motor
- ◆ sensitive for electrical failures

Figure 10b Types of Mill Drives (Central Drives)

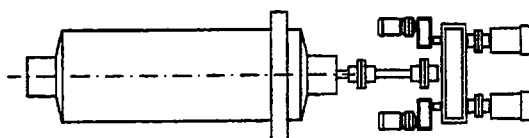
**Two way spur gear
with one motor**



**Two way spur gear
with two motors**



**Multi way spur gear drive
with two motors**



Planetary gear drive

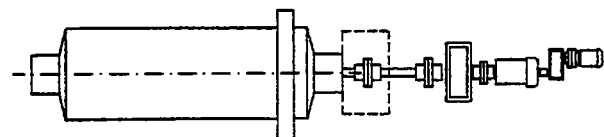
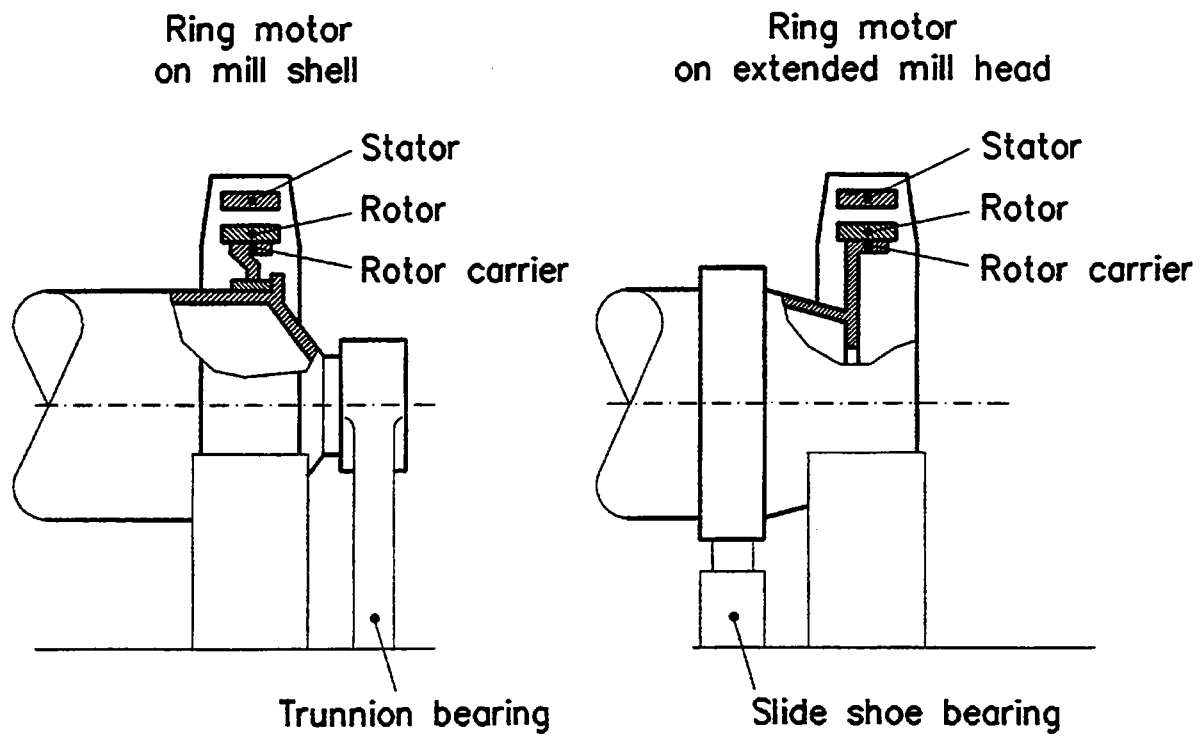


Figure 10c Types of Mill Drives (Gearless Drives)



5.6.5 Selection criteria for mill drives

For the proper selection of the type of mill drive following facts have to be considered:

- ◆ investment costs
- ◆ operation costs (e.g. gear efficiency)
- ◆ maintenance costs (e.g. lubrication)
- ◆ process requirements (e.g. mill discharge design)
- ◆ availability and reliability
- ◆ space requirement

The most important features of the various types of mill drives are summarized in Figure 11.

The latest tube mill installations show a trend toward the application of either double pinion Combiflex drives or central drives with a planetary gear.

A comparison of these two mill drives shows that the planetary gear drive has a good drive efficiency but also high investment costs whereas the efficiency of the Combiflex drive is low at lower investment costs.

Both mill drives permit the installation of rather high driving powers.

Figure 11 Selection Criteria for Mill Drives

FIG. 11 SELECTION CRITERIA FOR MILL DRIVES									
Type of mill drives		Range of power (MW)	500-2500 kW Drive efficiency (%) 1)		Investment costs 2)	Operation costs 3)	Maintenance costs 4)	Space requirement	Remarks
Girth gear	Single pinion	0,1 - 4	93	93,5	L	H	H	M	Small mills only
	Double pinion	1 - 5		92,5	L	H	H	M	Medium size mills with high drying capacity
	Double pinion (Combiflex)	2 - 10	92	92,5	L-M	H	L	L	Large mills with high drying capacity
Central drive	Two-way spur	1 - 3			M	M	M	M	Small mills only
	Multi-way spur	1,5 - 10	93	93,5	M	M	M	H	Not for mills with high drying capacity
	Planetary gear drive	3 - 10	94	94,5	H	L	L	L	
Gear less	Ring motor	< 4,5		92	H	H	L-M	L	Variable mill speed possible
Tube Mills								"HOLDERBANK" Process Technology Division CC-9545E 31.03.95	

6. INTERNAL ELEMENTS

6.1 Overview

6.1.1 Liners

The internal parts of a tube mill are protected by means of various types of wear resistance liners as can be seen in Figure 12. They have to assist the grinding function in the respective grinding compartment.

Liners need to have resistivity against impact forces (deformation, breakage), friction and corrosion.

Dry grinding mills are equipped with steel liners whereas wet grinding mills can alternatively be equipped with rubber liners.

6.1.2 Diaphragm

Diaphragms are installed to separate the grinding compartments. They have to be selected in such a way as to obtain the required retention time of the material in the former grinding compartment as well as to allow a sufficient flow of venting air or drying gases.

6.1.3 Grinding media

The sizes of the grinding media as well as the material quality are determined according to:

- ◆ material feed size
- ◆ product fineness
- ◆ mill diameter
- ◆ mill length
- ◆ grindability
- ◆ mineralogical structure of the material

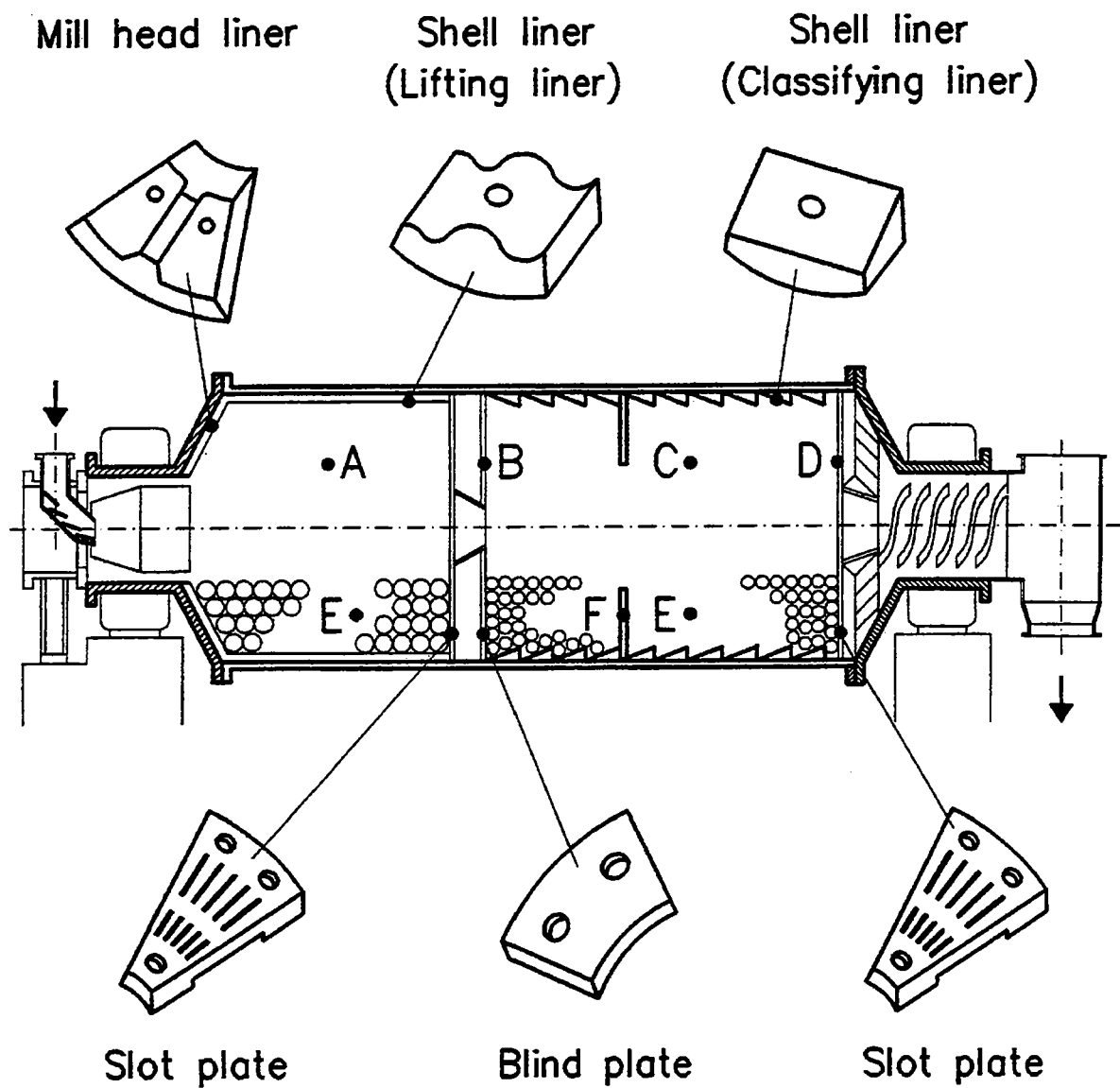
6.1.4 Retention rings

Cement mills in open circuits are often equipped with retention rings. The installed rings increase the rotating surface. More friction within the ball charge should result.

However an increase in grinding capacity has never been demonstrated.

Initiated further trials should show the effect of retention rings in one compartment slurry mills. At present time results are not available.

Figure 12 Overview Internal Elements



- A Coarse grinding compartment
- B Intermediate diaphragm
- C Fine grinding compartment
- D Discharge diaphragm
- E Grinding media
- F Retention ring

6.2 Head liners

Tube mill heads are built conical (with trunnion bearings) or even (with slide shoe bearings) as can be seen in Figure 13. Both types of mill head liners are exposed to high friction wear due to the relative movement between the liners and the grinding media. The liners of a conical mill head are additionally exposed to impact forces caused by the falling grinding media.

The wear ratio is not even across the liner rings and finds its maximum in the middle section of the liners.

Some mill head liners are designed with a radial rib in order to lessen the relative movement between the liners and the grinding media.

6.3 Shell liners

The following table shows the appearance forms of wear within the tube mills and the consequent requirement to the liner material.

Table

	Chamber 1 Coarse grinding	Chamber2 Fine grinding
Wear appearance within the tube mill		
Impact wear	High	Low
Friction wear	Low	High
Requirements to Liner Material		
Hardness	Low	High
Notch impact strength	High	Low

The selected material should further fulfill the following requirements:

- ◆ Homogenous hardening and homogenous structure composition throughout
- ◆ Low wear rate, no deformation and no breakage

Today's common material qualities, their composition and hardness and their field of application can be found in Figure 14.

High chromium alloy cast liners are the mostly used liner type due to their relatively good wear behaviour.

The hardness of the shell liners for the coarse grinding compartment is in general somewhat lower than the hardness of the respective grinding balls.

Figure 13 Head Liners

Conical mill heads
with two liner rings

Even mill heads
with three liner rings

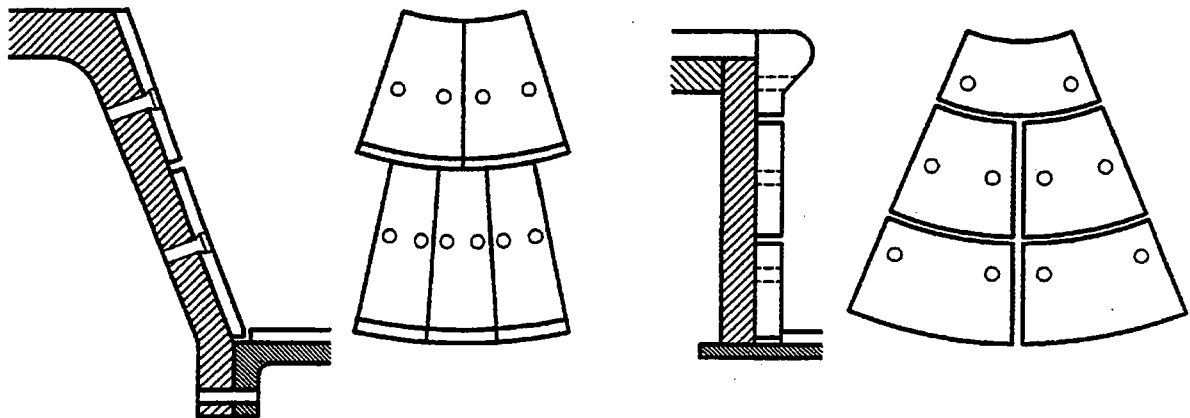


Figure 14 Material Quality and Application of Shell Liners

Material	Cem.comp.	Hardness (HRC)	Remarks
Manganese steel	12–14% Mn	40	Large mills deformation of liners Recommended for small mills (Initial surface hardness 20–25 HRC)
Low chromium alloy cast liners	2–3% Cr	40–42	Less deformation than manganese liners Suitable for big and small mills
High chromium alloy cast liners	12–15% Cr	50–55	Most used material Suitable for big and small mills (Notch impact strength 4–10 J/cm ²)

The exact measurements of the liners depend on the mill diameter. There is a norm (DIN 24111) describing the liners' length and width. Figure 15.

There are still many tube mills in the United States where the norm has not been considered yet.

It is the overall target of each liner design to reach:

- ♦ the lowest spec. energy consumption
- ♦ the highest production capacity of the tube mill

with the lowest possible specific costs for liners

6.3.1 Lifting liners

Lifting liners are applied in the coarse grinding compartment and in older mills, also in the fine grinding compartment. In the coarse grinding compartment the liners have to lift and release the grinding media in such a way that the impact will be strong enough to break the larger particles. The grinding media should not be overlifted, since some of them would fall on the bare liner and thus ball breakage and increased wear of liner and grinding media occurs.

In Figure 16 some of the most known types of lifting liners are shown.

Figure 15 DIN 24111

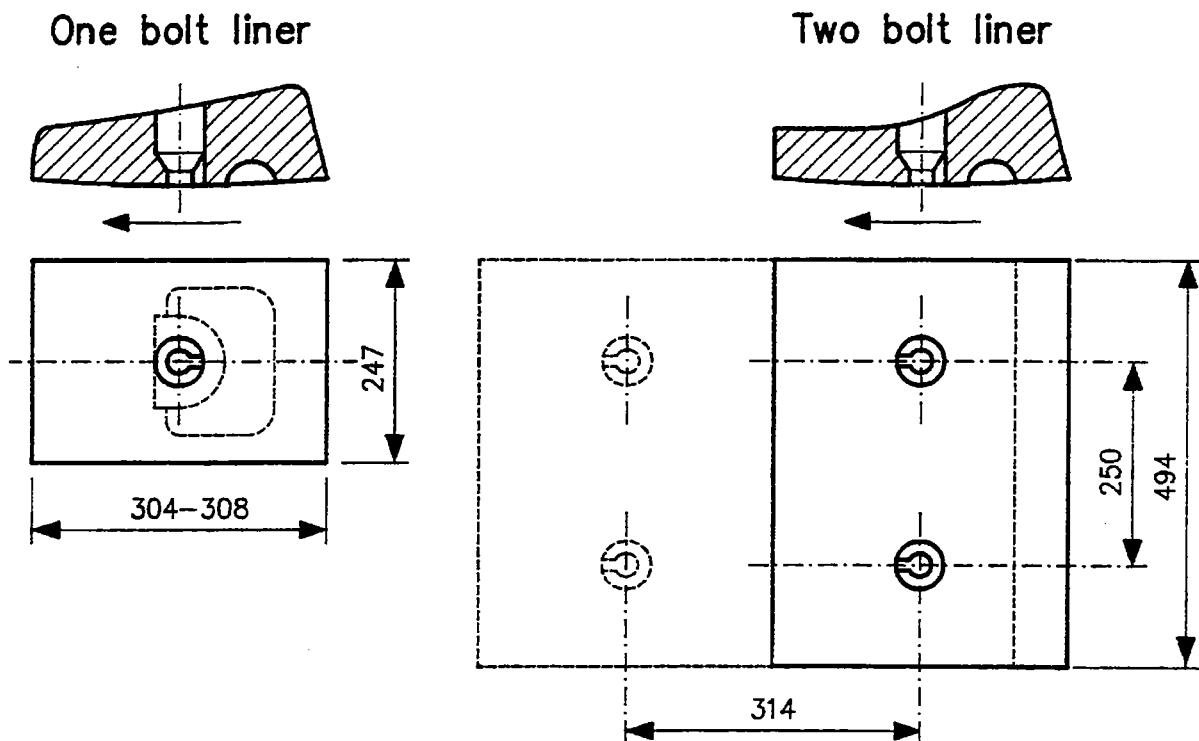


Figure 16 Lifting Liners

Double wave (Duolift)



Step liner



Activator



Step liner with structure



Lorraine type



6.3.2 Classifying lining

The fineness of the material increases towards the discharge of the fine grinding compartment due to the ongoing grinding process.

At the inlet of the fine grinding compartment the 'coarse' material requires larger balls for an efficient size reduction. Less friction but more impact forces are needed.

Toward the outlet of the fine grinding compartment smaller balls are required for the production of surface (friction).

Therefore, fine grinding compartments are often equipped with classifying liners. These liners automatically segregate the grinding media; i.e. the larger balls to the inlet end of the compartment with a progressive decrease in the ball size towards the outlet of the mill. The basic principle is shown in Figure 17.

The quantity and shape of classifying liners depend on the size of the mill.

Often a combination of different liners can be found within the fine grinding compartment e.g. at the inlet lifting and classifying liners and at the discharge where less impact forces are needed only classifying liners.

6.3.3 Lifting and classifying liners (combined)

Airswept mills consist of only one compartment. Since some of the feed material is rather coarse the grinding media consists also of bigger balls up to 80 mm. A normal classifying lining does not match to this ball size.

The lifting and classifying lining lifts the grinding media sufficient in order to grind also coarse material by impact forces. Due to the classifying function they also prevent the reverse classification of the ball charge.

Airswept mills are equipped with lifting and classifying lining over the whole compartment length or only in the first third. The remaining two thirds of the compartment are then lined with regular classifying liners.

Figure 17 Classifying Lining

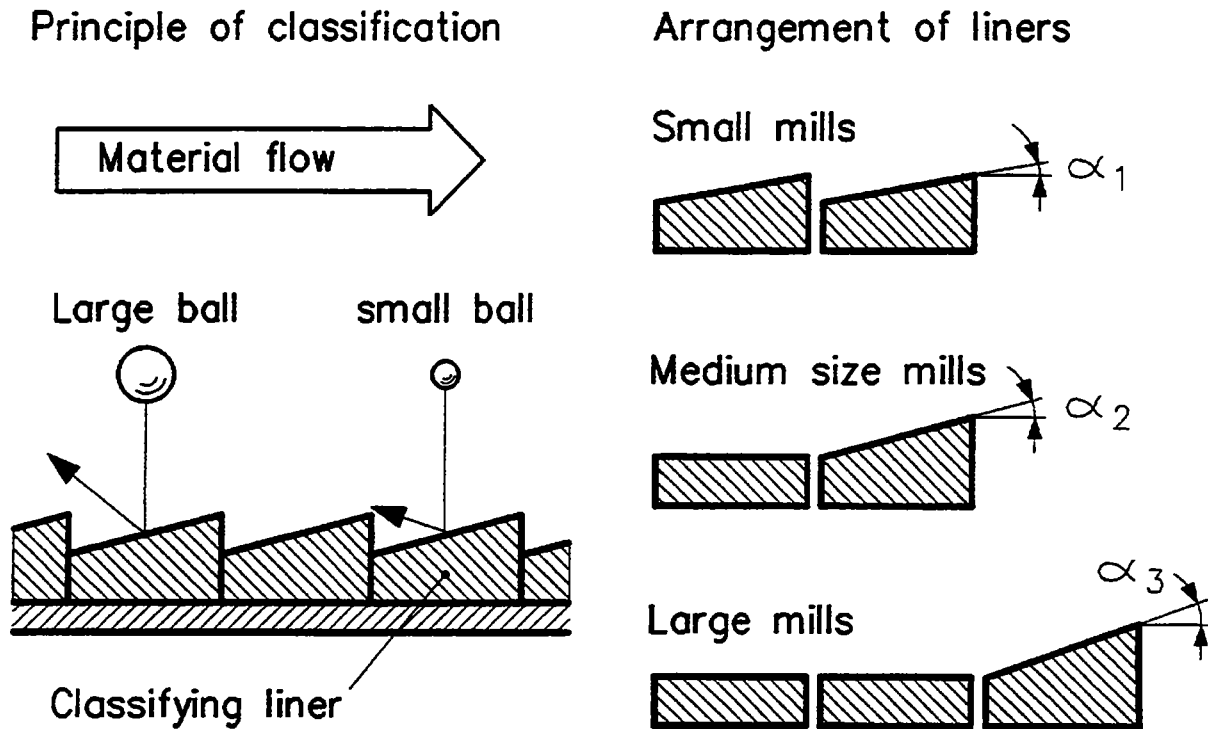
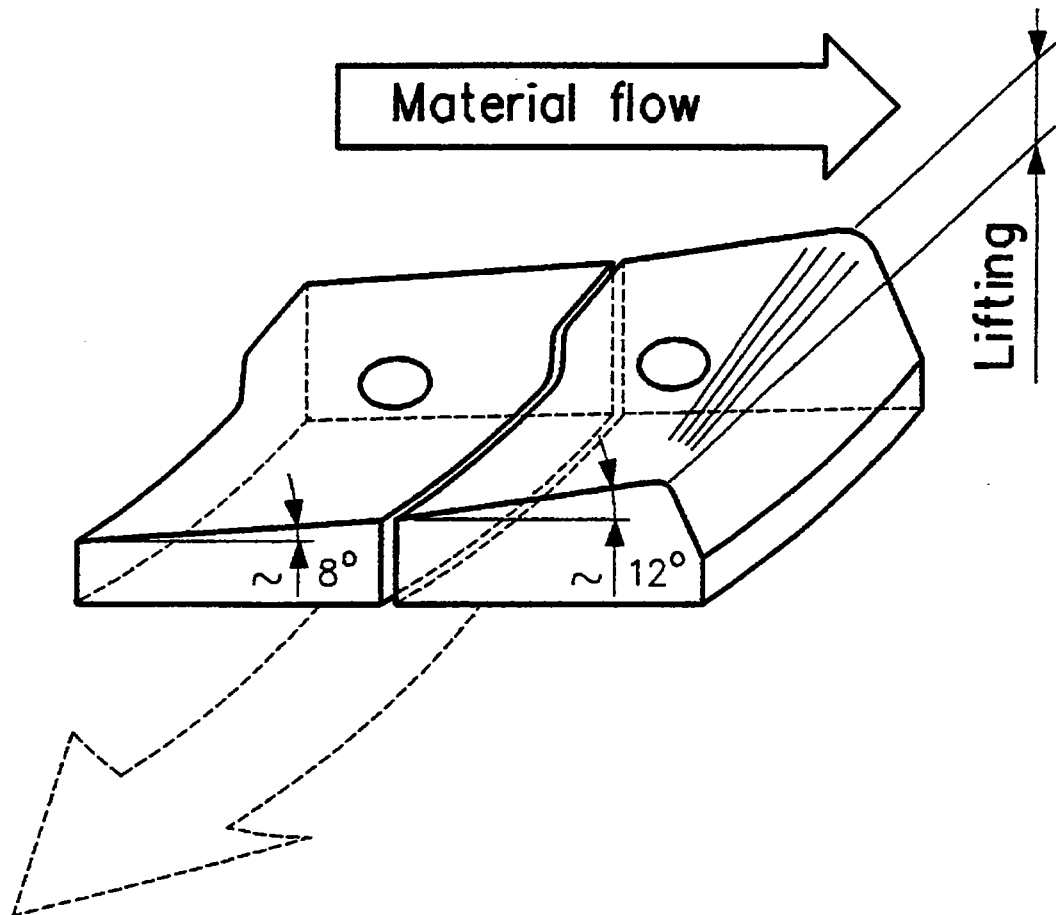


Figure 18 **Lifting and Classifying Liners**



Rotation

6.3.4 Other liner types

6.3.4.1 *Dragpeb*

FLS supplies compartment 2 of its tube mills with either classifying lining or the so-called Dragpeb lining. The philosophy of this type of liners (Fig 19) is the maximum utilization of the mill diameter.

The mill capacity changes exponential with the mill diameter $D^{2.5}$. Therefore, the Dragpeb liners are very thin (~ 40 mm high) to have the largest possible internal diameter.

The Dragpeb liners do not classify the ball charge. For this reason the advantage of a classified ball charge as described in chapter 6.3.2 can not be applied.

6.3.4.2 *Grooved liners*

The philosophy of this liner type is to maximize the contact zone between the outer layer of the ball charge and the liners.

Figure 19 shows that the material between the liners and the balls can not escape due to the grooved liner shape.

There are also grooved liners available which have a classifying effect. The expected better efficiency has never been proven in direct comparisons to other mill liners.

6.3.5 Fastening and installation of liners

The mill shell lining can be divided according to the method of fastening into three groups:

- ◆ bolted mill lining
- ◆ bolt saving mill lining
- ◆ boltless mill lining

The boltless or bolt saving lining has compared to the conventional bolted liner the following advantages:

- ◆ longer lifetime of liner due to elimination of fastening hole where wear generally starts
- ◆ elimination of mill shut-downs due to bolt breakages
- ◆ no leakage in mill shell due to untight fastening

Bolted mill lining

The bolted mill liners are fastened to the mill shell either by one or by two bolts depending on the plate size.

Bolt saving mill lining

To decrease the number of bolts also a bolt saving fastening according to Figure 20 can be applied. The bolted liners are located in an angle of 90 ° to each other.

Boltless lining

The boltless lining is self-supported. First the lower half of the mill is lined and the endliners braced with jacks; the mill is then rotated to facilitate lining of the other half of the mill. The installation should always be supervised by the supplier.

Figure 19 Other Liner Types

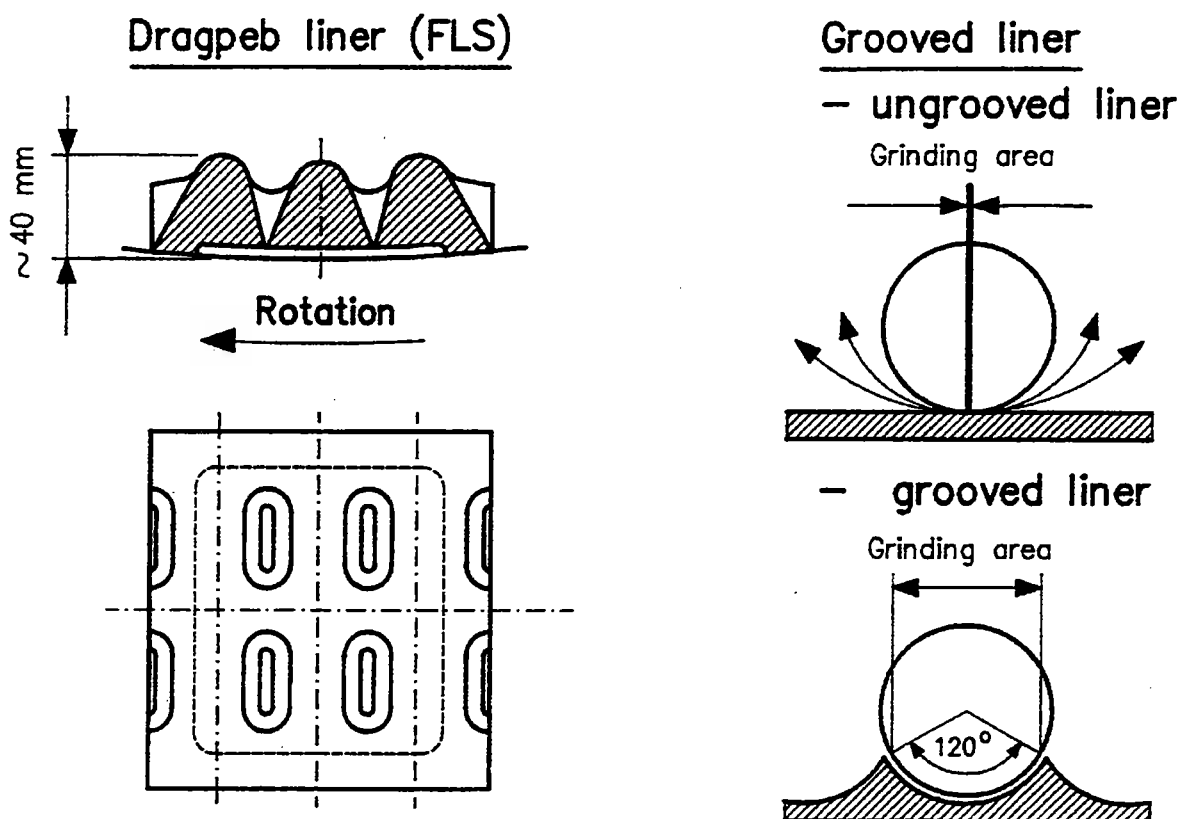
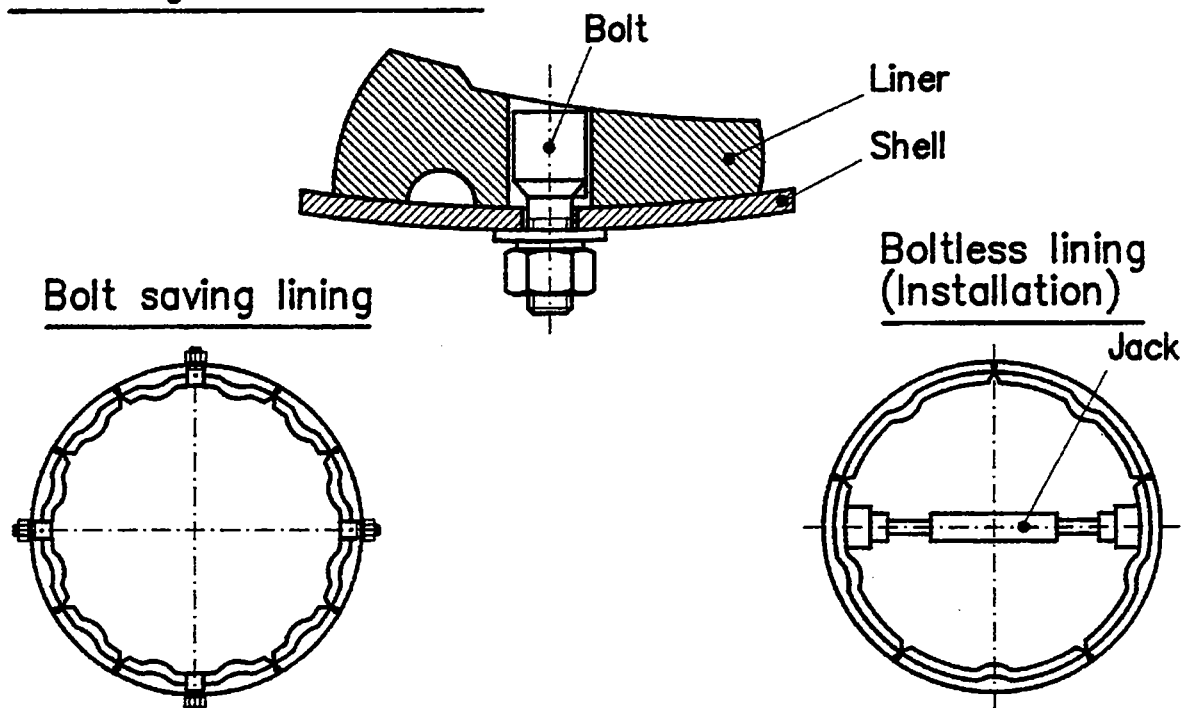


Figure 20 Fastening and Installation of Liners

Fastening of bolted liner



6.3.5.1 Life times of shell liners

High chromium alloyed cast steel is mostly used for the fabrication of the shell liners. The life time of this typical wear part depends on the type of material being ground.

Some ranges of the expected life times for high chromium liners can be found in Figure 21.

Some of the additives such as pozzolana or slag can cause high wear. They often are not only very abrasive but also consist of high moisture which increases the wear rates due to corrosion.

6.3.6 Rubber liners

Rubber lining is applied in wet grinding mills.

A comparison to steel liners shows the advantages and disadvantages of such a lining:

♦ Advantages:

- low noise
- less liner weight
- easier installation
- good abrasion resistance
- more economical in combination with small balls due to less liner wear costs at smaller ball sizes as can be seen in Figure 22

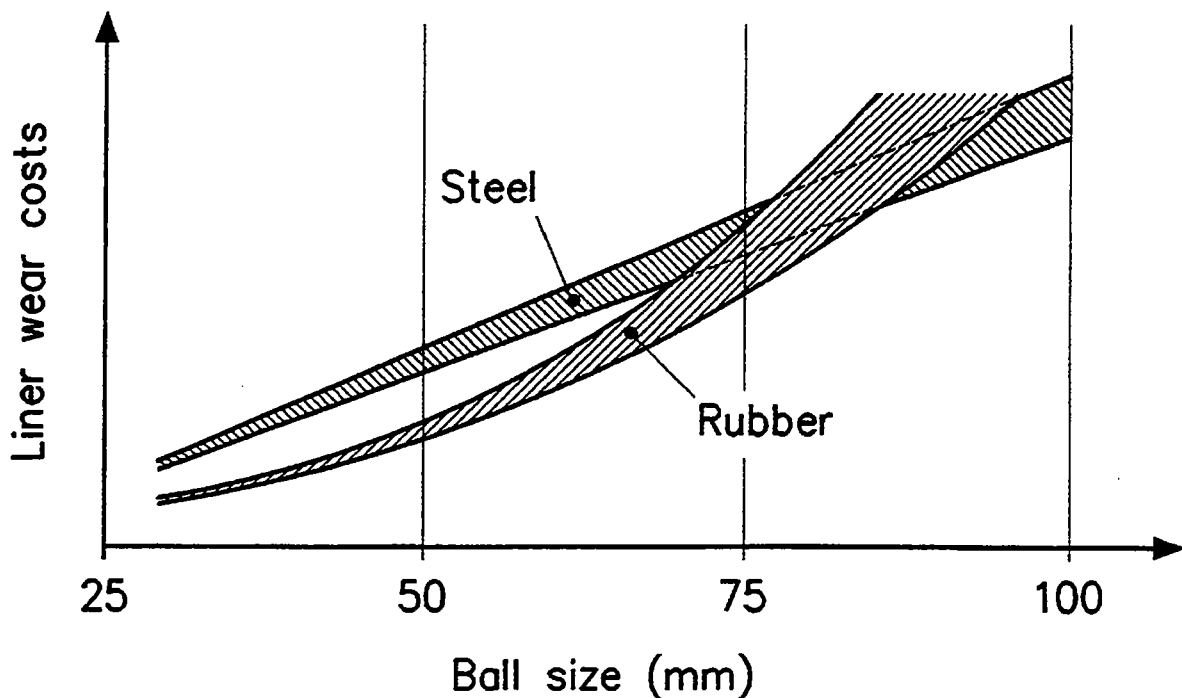
♦ Disadvantage:

- limited ball size (excessive increase of wear rate with bigger balls)
- bigger liners -> less volume -> less grinding capacity
- maximum operation temperature of 80 ° C (no dry grinding possible).

Figure 21 LifeTime Of Shell Liners

Material	Hours of life time	
	Coarse grinding compartment	Fine grinding compartment
Raw meal (12–14% R 90 μm 2–4% free quartz)	30'000–40'000	60'000–80'000
Portland cement (3'000 cm^2/g)	25'000–30'000	50'000–60'000
Portland cement with minor additives	23'000–27'000	46'000–54'000
Composite cement	15'000–17'000	30'000–34'000

Figure 22 Rubber Liners



6.4 Intermediate diaphragm

They consist of the following elements (double diaphragm):

- ◆ slotted plates
- ◆ centre screen
- ◆ supporting structure
- ◆ blind plates
- ◆ lifters

Diaphragms can be located at following places:

- ◆ between a drying and grinding compartment
- ◆ between a coarse and fine grinding compartment
- ◆ at the mill discharge of either end or centre discharge mills

6.4.1 Function

The intermediate diaphragm subdivides the mill in a coarse grinding and fine grinding compartment. In order to maintain the grinding efficiency along the length of the mill a graduation of the grinding media is required.

The material ground in the first compartment passes through the slots of the intermediate diaphragm and enters the next grinding compartment.

Adjustable diaphragms permit to control the material flow. They keep as much material in the compartment as required for the highest grinding efficiency. Figure 23 shows the working principle of an adjustable diaphragm.

Up to the diaphragm the fed material should be ground to a size smaller than the slot width. Oversized material is retained in the coarse grinding compartment until it is sufficiently ground.

The most important design criterias for intermediate diaphragms are the slot width and the total slot area (open area).

6.4.2 Single diaphragm

Single diaphragm consist of :

- ◆ slotted plates
- ◆ centre screen

They are installed as separation between coarse grinding and fine grinding compartments of smaller mills (Fig. 24).

The centre piece is built either open with a screen or closed.

The single diaphragm is also applied as discharge diaphragm for centre discharge mills as shown in Figure 24.

Figure 23 Function of a Intermediate Diaphragm

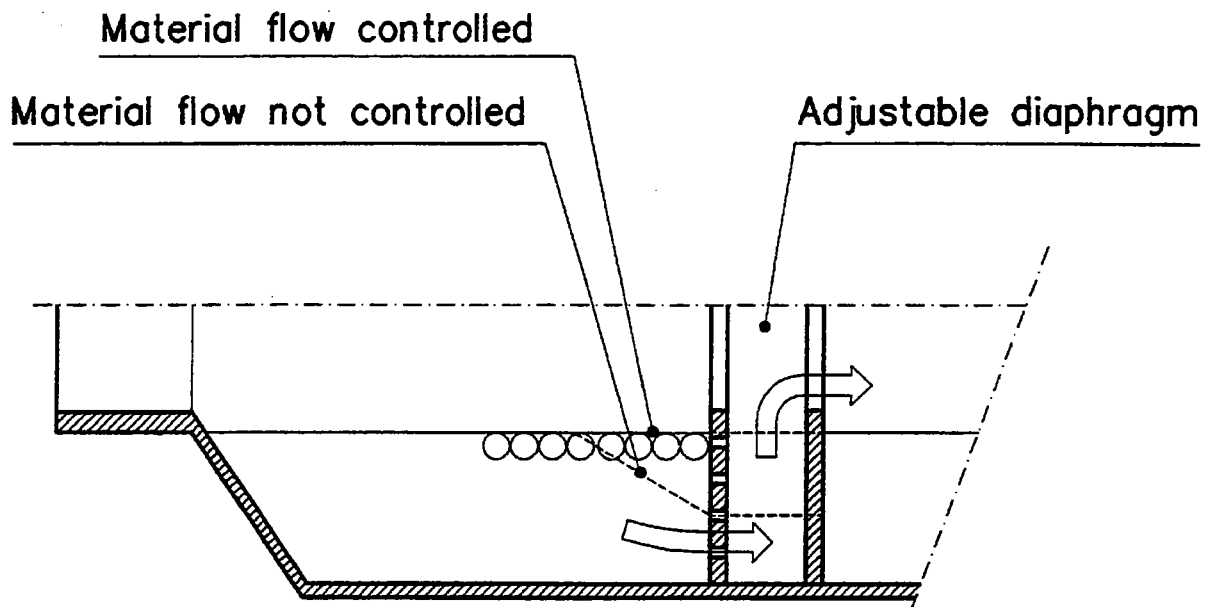
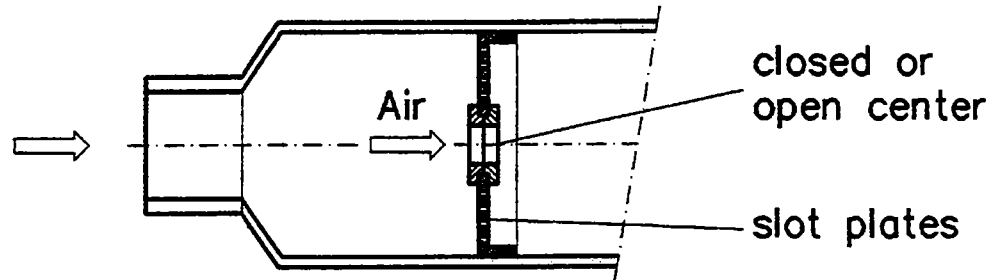
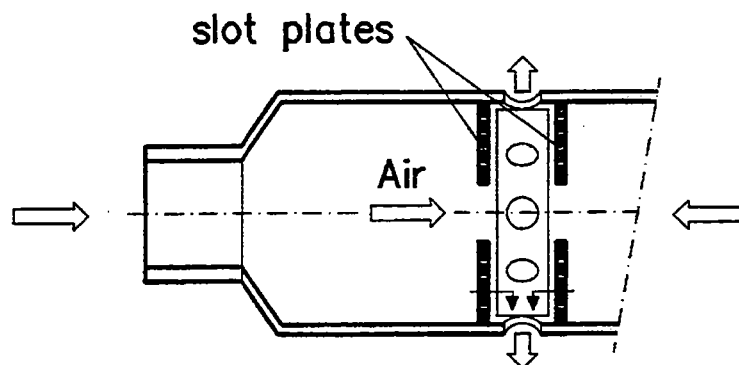


Figure 24 Single Diaphragm

Single diaphragm as intermediate diaphragm of small mills



Single diaphragm for centre discharge mills



6.4.3 Double diaphragm

6.4.3.1 *Double diaphragm with lifters*

Double diaphragms consist of slot plates on the inlet side and of blind plates on the outlet side. The diaphragm is furthermore equipped with lifters to transport the material (Fig. 25).

The lifters are either straight or curved. The centre part of the diaphragm is open to allow a sufficient passage of venting or drying air through the mill.

6.4.3.2 *Double diaphragm system Combidan (FLS)*

The Combidan diaphragm from FLS consists at the inlet side instead of slot plates of a screen which covers the whole mill cross section.

This relatively thin screen is protected against the impact of the large grinding balls by solid, highly wear-resistant protection plates. They are spaced to allow preground material but not grinding media to pass into the short separation compartment between the solid liners and the screen.

6.4.4 Adjustable diaphragm

The grinding efficiency of a mill is greatly affected by a proper retention time of the material in the first chamber.

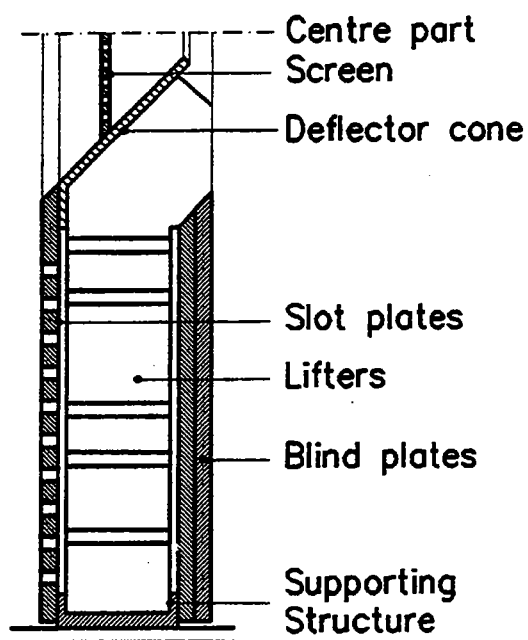
There is a various number of material flow control systems available. All systems are generally based on the same working principle which controls in one way or the other the material flow from the first to the second chamber.

Slegten and Voest Alpine have instead of fix installed lifting plates adjustable scoops and Pfeiffer controls the material flow by changing the open area with an adjustable tube.

Some of the main systems are shown in Figure 26.

Figure 25 Double Diaphragm

Double diaphragm with lifters



Double diaphragm
System combidan (FLS)

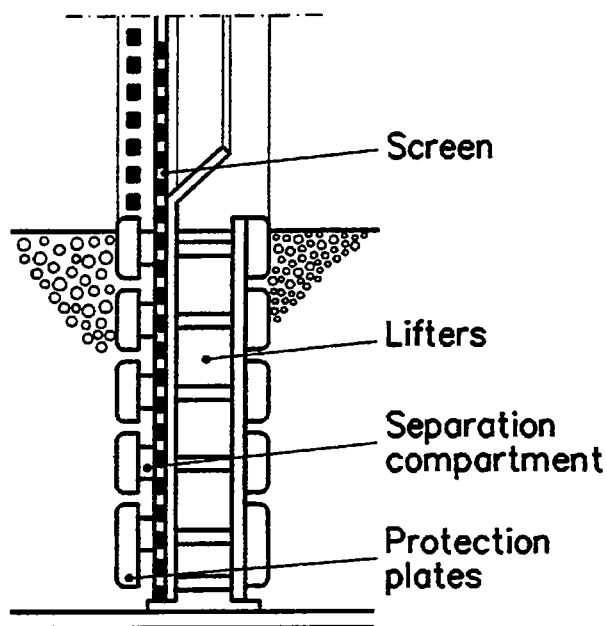
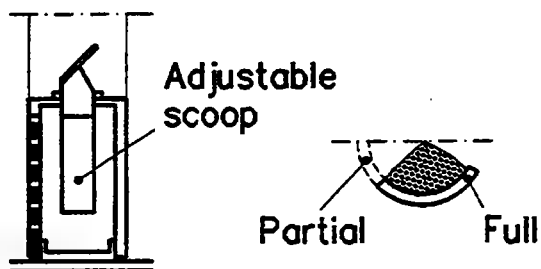
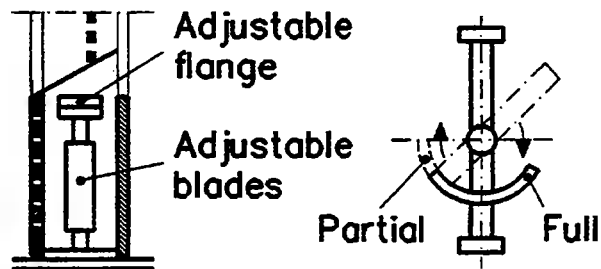


Figure 26 Adjustable Diaphragm

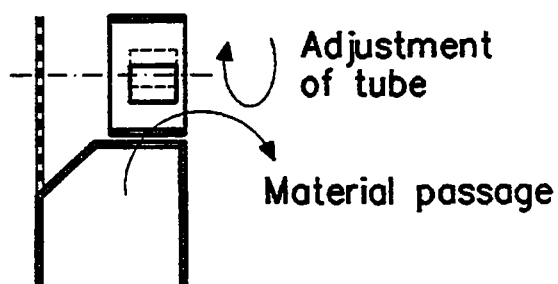
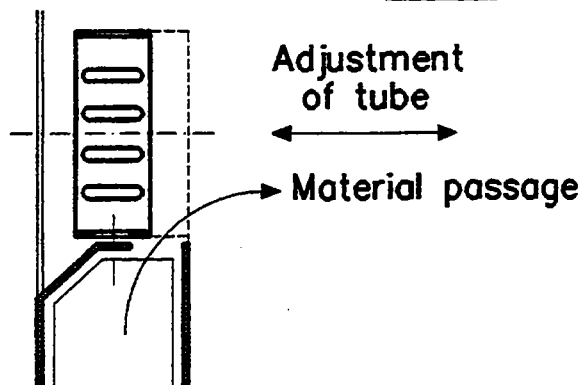
Slegten



Voest Alpine



Pfeiffer



6.4.5 Open diaphragms (Drying chamber diaphragm)

Open diaphragms (Fig. 27) are installed as separation between drying and coarse grinding compartment. Therefore they are often called drying chamber diaphragms.

The liner slots have to be large enough to allow the transfer of the material and the drying gas through the diaphragm.

The diaphragm is on the drying compartment side open and has to resist the forces coming from the ball charge of the grinding compartment.

In operation with hot gases the temperature on the diaphragm can go up to 400 °C. The diaphragm needs to be shock resistant also at high temperatures.

6.4.6 Slots (Intermediate diaphragm)

On the inlet side the intermediate diaphragms are provided with slot plates made of wear resistant steel. The slot width depends on:

<u>the material to be ground</u>	compartment length
ball size	mill venting air rate

Some typical examples are shown in Figure 28.

The slot design must be in such a way that they fulfill the following conditions:

- ◆ constant slot width also with continuous wear
- ◆ low restriction to air and material flow
- ◆ resistance to slot breakage
- ◆ no clogging of slots by particles or due to impacts from the grinding balls

The slots are arranged radially or tangentially to the mill axis whereas radial slots are reducing the possibility of clogging and tangential slots yield a better material flow through the diaphragm.

6.4.7 Wear rate and life time of diaphragms

The slot plates are either made from special hardened wear resistant rolled steel, or they are made from high chromium castings. Some main features of both types of material are listed below.

Material	Cr content	Surface hardness
High chromium alloyed casting	up to 27 %	60 HRC
Rolled steel	low	50 - 60 HRC

The wear rate resp. life time of a diaphragm depend on the type of material being ground. Some guide figures are given in the table below.

Material	Life time [h]
Raw material (15 % R 90 μm ; 17 kWh/t)	10'000 - 15'000
Clinker (2800 cm ² /g; 30 kWh/t)	8'000 - 10'000

The slot plates are from the life time point of view the weakest point of the mill.

Figure 27 Open Diaphragm (Drying Chamber Diaphragm)

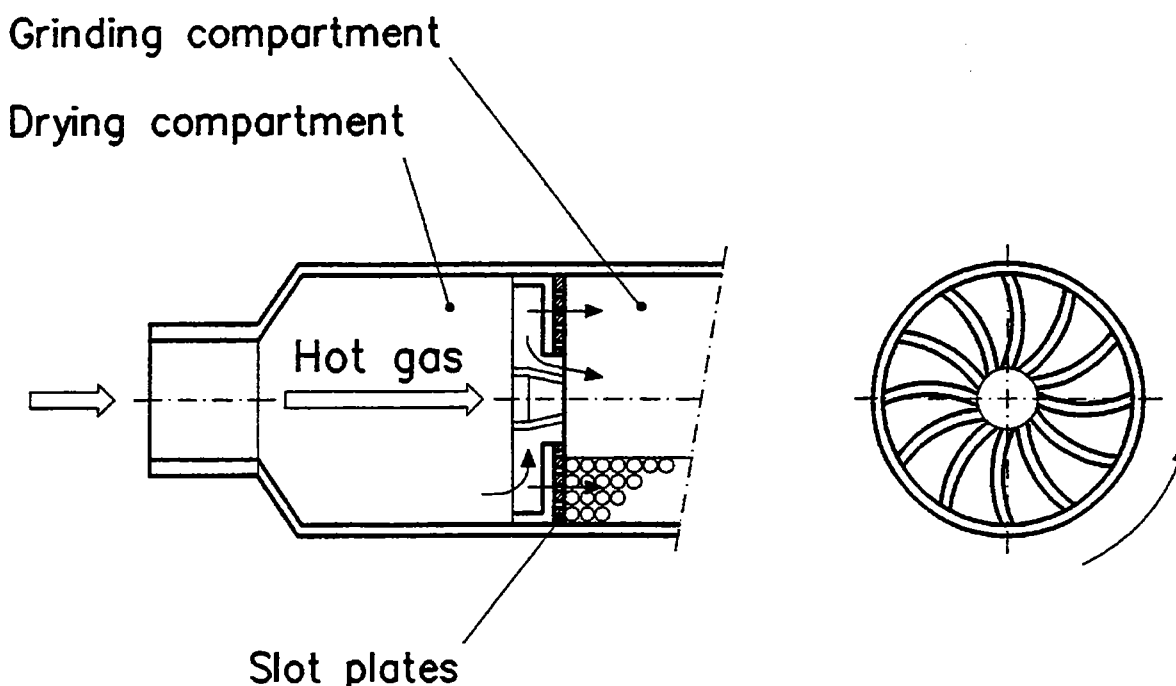
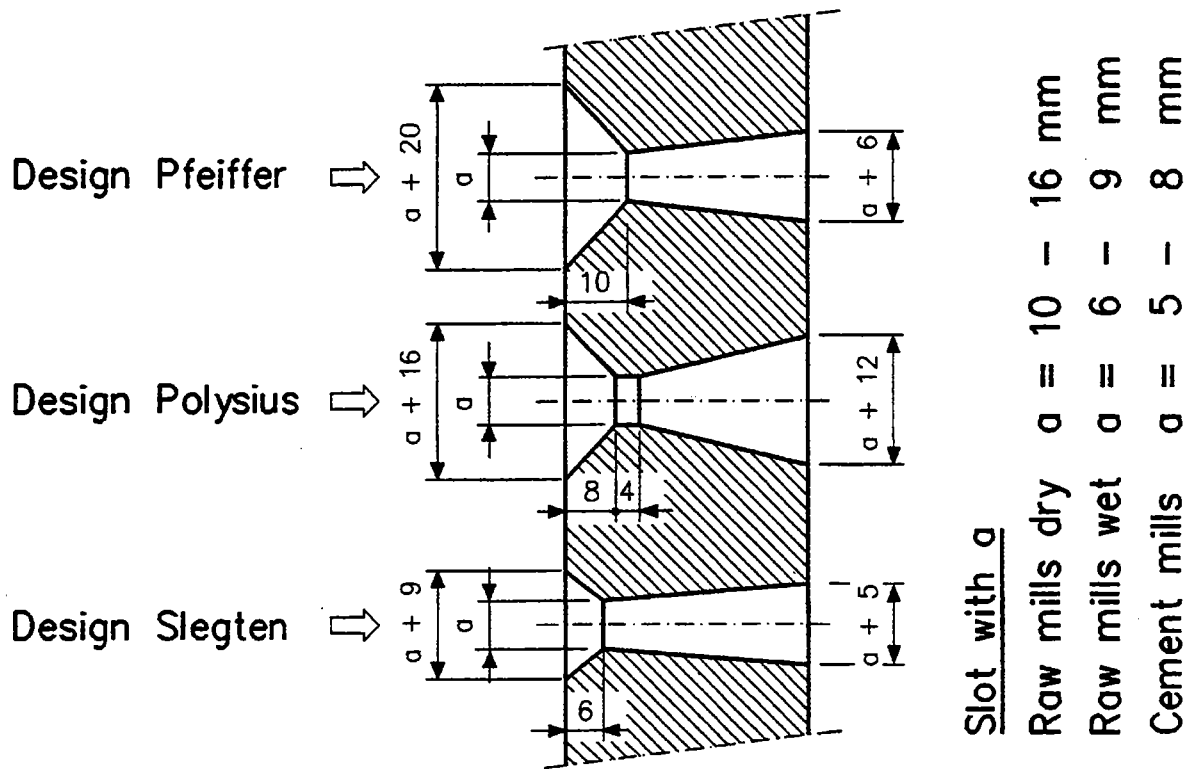


Figure 28 Slot Design for Diaphragm



6.5 Discharge diaphragm

Discharge diaphragms are installed at the outlet of an end discharge mill or are placed in the centre of a centre discharge mill.

The main components of a discharge diaphragm are shown in Figure 29. They are equipped with lifters and cones similar to the double diaphragm.

6.5.1 Diaphragm for centre discharge mills

The discharge diaphragm of a centre discharge mill consists of two single diaphragm which are installed at the outlet of the coarse and fine grinding compartment.

The difference between these two single diaphragms are their slot widths. Normally the slots at the outlet of the fine grinding compartment are about two millimeters wider than the slots at the outlet of the coarse grinding compartment.

6.5.2 Combidan discharge diaphragm

The Combidan mill outlet (FLS) differs from the other known discharge designs (Fig. 30).

A very small outlet compartment is added to the fine grinding chamber. A dam ring equipped with liners protects the outlet screen from wear caused by the ball charge.

Figure 29 Discharge Diaphragm

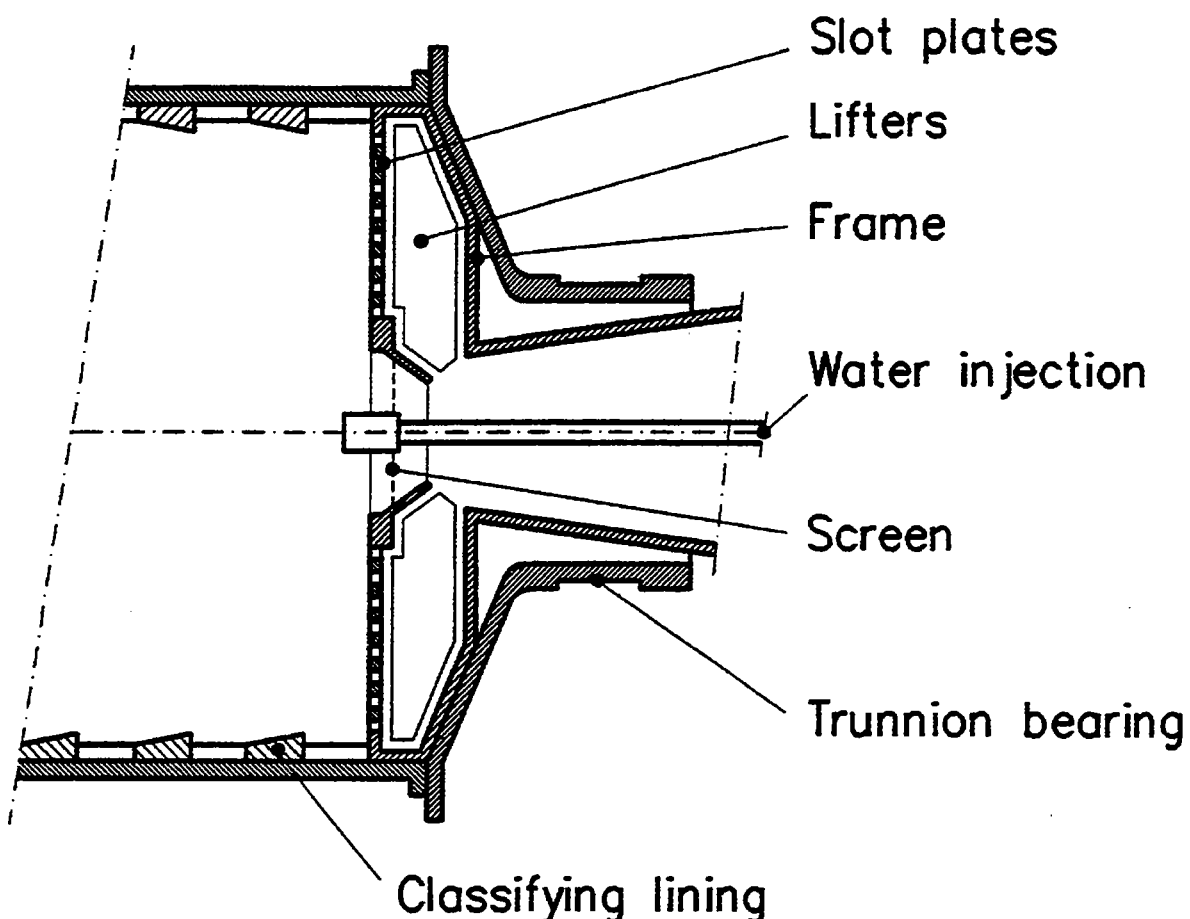
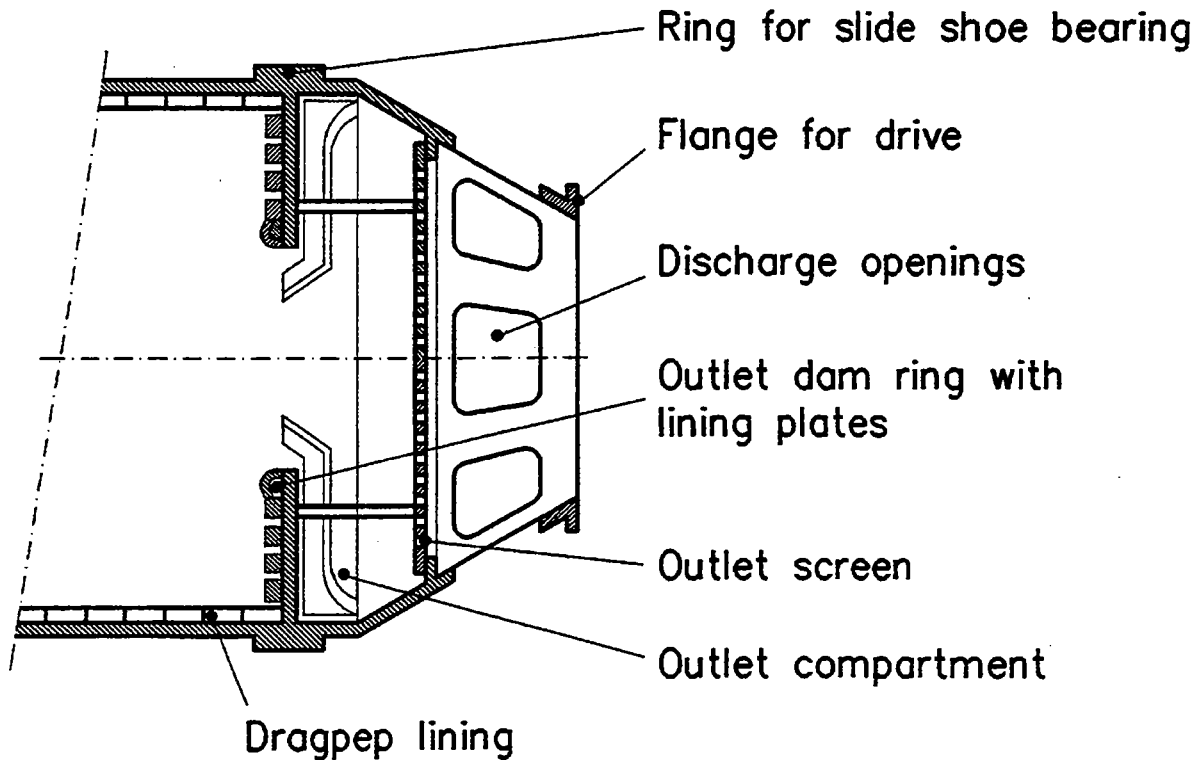


Figure 30 Combidan Discharge Diaphragm



6.5.3 Adjustable discharge diaphragm for slurry mills

This discharge diaphragm for slurry mills consists of slot plates, structure and an adjustable cone (Fig. 31).

Depending on the position of the cone the material level inside the diaphragm and grinding chamber stays from low to high, i.e. the material level in the chamber of slurry mills can be adjusted.

The correct amount of slurry in the grinding compartment has the following advantages:

- ◆ low wear rate on liners and grinding media
- ◆ good use of the grinding compartment

6.5.4 Slots (discharge diaphragm)

The slots for the discharge diaphragm are normally wider than those for the intermediate diaphragm but also depend on the material to be ground and the size of the smallest balls in the grinding chamber.

Following guide values for slot width can be given:

- ◆ Raw mills (dry) 12 - 18 mm
- ◆ Slurry mills (wet) 8 - 11 mm
- ◆ Cement mills 7 - 10 mm

6.5.5 Wear rate and life time of discharge diaphragm

The wear at the discharge diaphragm is caused by friction forces between the grinding media and the diaphragm or the material and the diaphragm.

Since there is no heavy impact on the plates the wear rate is lower than the wear rate on the intermediate diaphragm.

Figure 31 Adjustable Discharge Diaphragm for Wet Grinding

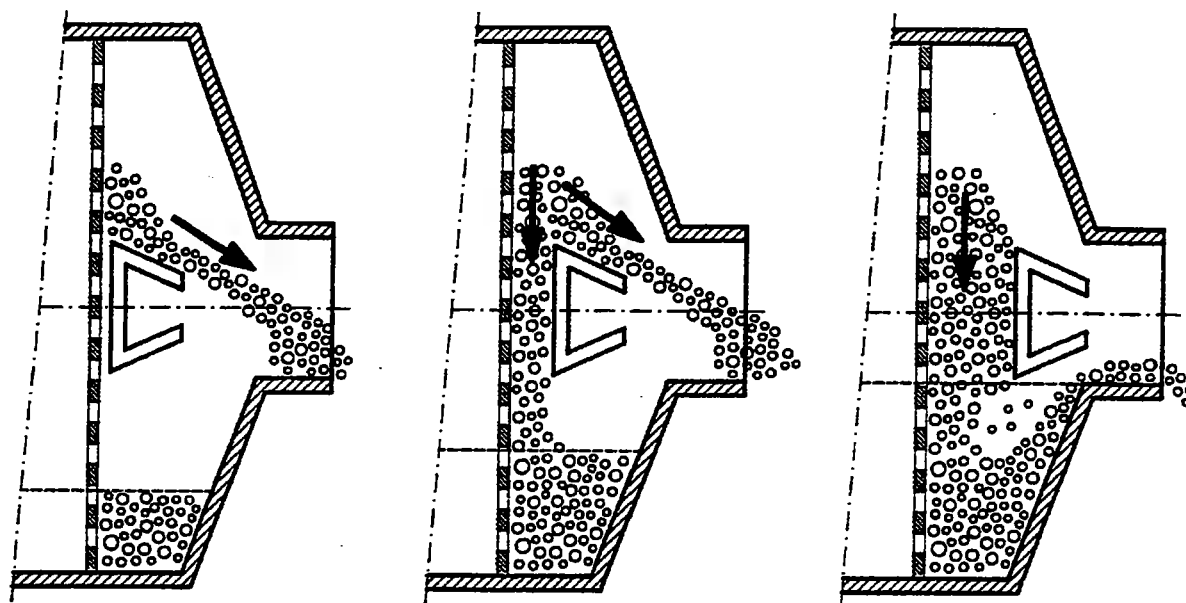
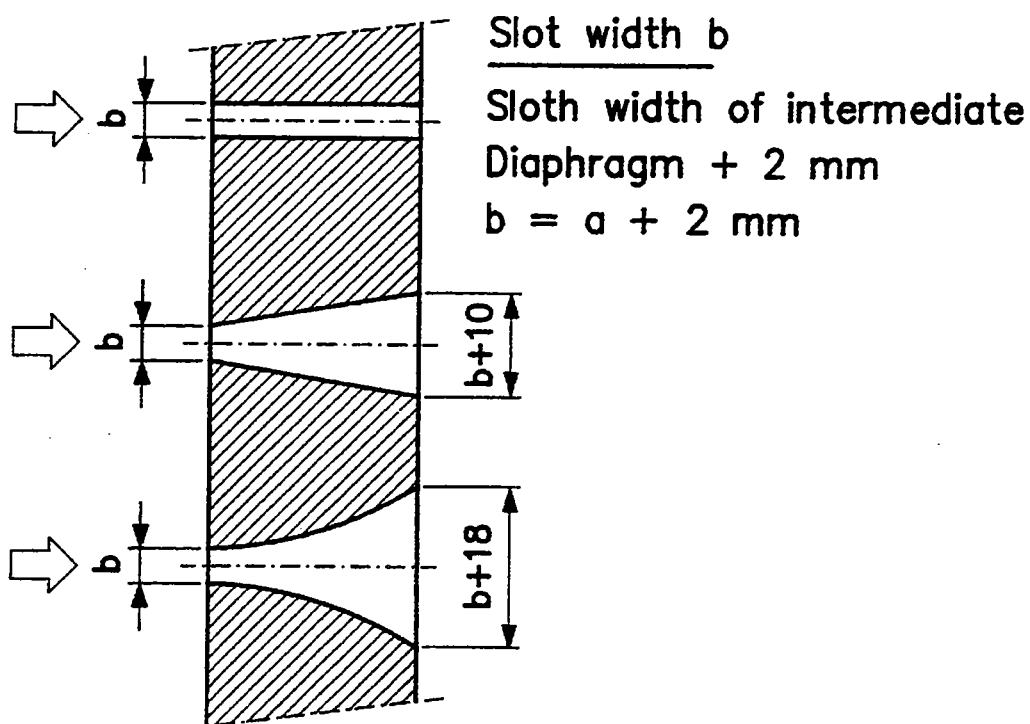


Figure 32 Slot Design For Discharge Diaphragm



6.6 Grinding media

6.6.1 General

The ball charge of a mill consists of grinding balls of several sizes and of different material qualities.

For coarse grinding normally balls between 50 and 100 mm and for fine grinding balls between 15 and 50 mm are used. The maximum and minimum ball size and the composition depends on various factors, such as:

- ◆ max feed size of material to be ground
- ◆ product fineness
- ◆ mill diameter, mill length
- ◆ grindability and mineralogical structure of the feed material
- ◆ mill system (open/closed circuit, number of compartments, circulating load)

Depending on the grinding process resp. grinding step the balls have to resist:

- ◆ impact forces by the balls themselves (specially in coarse grinding with big balls)
- ◆ wear caused by friction forces between the balls and the liners
- ◆ wear caused by abrasive materials
- ◆ corrosion

To maintain a constant and optimum mill output, the selection of the adequate ball sizes as well as of the respective material quality has to be done very carefully.

6.6.2 Material quality

The mill can be filled either with cheap low quality balls with high wear rates or with expensive high quality balls with lower wear rates. It has to be considered, however, that low quality balls also call for more frequent recharging of the mill in order to replace the worn grinding media, thus resulting in a lower utilization rate of the mill and higher maintenance costs.

The material qualities as shown in Figure 33 are applied for the grinding media.

Due to their good wear resistancy a clear trend toward the use of high chromium cast iron quality balls is observable.

Figure 33 Material Quality of Grinding Media

Material quality	Chemical composition	Feature
Forged grinding media	0,5 – 1,0 % C 0,8 – 1,2 % Mn 0,8 – 12,0 % Cr	- Available everywhere at favourable prices - Applied for not too abrasive materials - Hardness 25–65 HRC (surface only)
White cast iron	2,8 – 3,3 % C 0,1 – 0,4 % Mn 0,1 – 0,4 % Cr 0,4 – 0,8 % Si	- Specially used for wet grinding - Large quality variations - Only for mills < \varnothing 3,5 m - Only for fine grinding - Hardness : 45–50 HRC
High chromium cast iron	Raw grinding dry 2,0 – 3,0 % C ~ 12,0 % Cr Raw grinding wet 20,0 – 30,0 % Cr Cement grinding 2,0 – 3,0 % C 12,0 – 17,0 % Cr	- Very wear resistant - Hardness : 48–68 HRC (throughout)

6.6.3 Wear rate

The wear of the grinding media is caused by:

- ♦ impact
- ♦ friction forces
- ♦ abrasiveness of the material
- ♦ corrosion

Grinding media (e.g. balls and cylpebs) are either forged or are cast from wear resistant high chromium steel. Depending on the quality of the grinding media wear rates of 15 - 1200 g per ton of material can be expected.

Considering the material qualities as mentioned in the last chapter the specific wear rates as listed in Figure 34 could be expected. Following assumptions were made:

- ♦ Raw material ~ 17 kWh/t, 10 - 15 % R 90 μ m
- ♦ Slurry ~ 10 kWh/t, 10 - 15 % R 90 μ m
- ♦ Cement ~ 30 kWh/t, 3000 cm²/g

Balls in white cast iron quality can not be used in coarse grinding compartments due to the danger of ball breakage.

The wear rates given for cement consider only portland cement. For composite cements where parts of the clinker are replaced by additives such as slag, pozzolana, etc. the wear rates can be much higher, e.g. ~200 g/t grinding a pozzolana cement with high chromium balls.

Figure 34 Specific Wear Rates of Grinding Media

Material quality	Unit	Specific wear rate					
		Raw material		Slurry		Cement ①	
		Small balls	Large balls	Small balls	Large balls	Small balls	Large balls
Forged balls	g/kWh	2 – 10	10 – 30	15 – 50	20 – 80	2 – 15	10 – 40
	g/t	30 – 170	170 – 500	150 – 500	200 – 800	60 – 450	300 – 1200
White cost iron balls	g/kWh	2 – 6	–	20 – 60	–	5 – 15	–
	g/t	35 – 100	–	200 – 600	–	150 – 450	–
High chromium balls	g/kWh	1 – 3	2 – 5	10 – 20	15 – 30	0,5 – 1,5	1 – 2
	g/t	15 – 50	30 – 80	100 – 200	150 – 300	15 – 50	30 – 70

① Portland Cement

